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ENGINEERING AND DESIGN

Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites

ENGINEER MANUAL

CEMP-RT/ CECW-EG Engineer Manual 1110-1-4000	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-1-4000 1 November 1998
	Engineering and Design MONITORING WELL DESIGN, INSTALLATION, AND DOCUMENTATION AT HAZARDOUS TOXIC, AND RADIOACTIVE WASTE SITES	
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CEMP-RT CECW-EG	**DEPARTMENT OF THE ARMY** **U.S. Army Corps of Engineers** **Washington, DC 20314-1000**	EM 1110-1-4000
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Engineering and Design
MONITORING WELL DESIGN, INSTALLATION, AND DOCUMENTATION AT HAZARDOUS TOXIC, AND RADIOACTIVE WASTE SITES

1. Purpose. This Engineer Manual (EM) provides the minimum elements for consideration in the design, installation, and documentation of monitoring well placement (and other geotechnical activities) at projects known or suspected to contain chemically hazardous, toxic, and/or radioactive waste.

2. Applicability. This EM applies to all U.S. Army Corps of Engineers (USACE) commands having hazardous, toxic, and radioactive waste (HTRW) project responsibilities. For special considerations of radioactive, biological, or mixed (chemical and radioactive) waste components, contact the USACE Hazardous, Toxic, and Radioactive Waste (HTRW) Center of Expertise (CX) in Omaha, Nebraska.

3. References. References are provided in Appendix A.

4. Distribution Statement. Approved for public release, distribution is unlimited.

5. Discussion. The technical understanding and evaluation of HTRW studies involves an appreciation of the interactions between geology, hydrology, geotechnical engineering, and chemistry. This scenario is complicated by the trace (low parts per billion) levels of regulated chemical species that are detectable in the environment and when detected or suspected may trigger intricate and costly response actions. Slight deviations from prescribed drilling, well installation, sampling, or analytical procedures may bias or invalidate both the reported concentrations of these regulated species and the technical basis upon which the Corps makes decisions. These relationships are further complicated by the heterogeneous, anisotropic character of the natural environment itself. This situation requires environmental characterization based upon procedures that are standardized, documented, understood, and followed. This manual outlines that effort.

FOR THE COMMANDER:

2 Appendices
App A - References
App B - Abbreviations

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This manual supersedes EM 1110-1-4000, dated 31 August 1994.

CEMP-RT

DEPARTMENT OF THE ARMY
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Chapter 1
Introduction

1-1. Purpose

This Engineer Manual (EM) provides geotechnical and chemical guidelines for U.S. Army Corps of Engineers (USACE) elements in the planning, installing, and reporting of soil and/or bedrock borings, monitoring wells, and other geotechnical and geochemical devices at hazardous, toxic, and radioactive waste (HTRW) sites. These guidelines are a compilation of those procedures necessary for the acquisition of environmentally representative geotechnical data and samples, using conservative methods documented in a comprehensive manner.

1-2. Applicability

a. This EM applies to all USACE commands, elements and their contractors (including architect-engineers, [AE's]) having military and/or civil works hazardous, toxic and radioactive waste (HTRW) site responsibilities and/or engaged in programs within the Comprehensive Environmental Resource, Compensation, and Liability Act (CERCLA); the Resource Conservation and Recovery Act (RCRA); the Superfund Amendments and Reauthorization Act (SARA); the Defense Environmental Restoration Program (DERP); non-mission HTRW work for other (non-Corps) offices; work within host nation agreements; or any other Corps-managed HTRW activities.

b. Only HTRW work involving *chemical* issues are covered within this manual. Biological waste components of HTRW are not addressed. Supplemental instructions will be provided as appropriate procedures are identified. In the interim, any requests for assistance in those areas should be directed to the Hazardous, Toxic, and Radioactive Waste (HTRW) Center of Expertise (CX) within the U.S. Army Engineer District, Omaha (CENWO), Attention: HTRW - Center of Expertise, Geoenvironmental & Process Engineering Branch (CENWO-HX-G); or Headquarters, U.S. Army Corps of Engineers (HQUSACE), Attention: Directorate of Military Programs, Policy and Technology Branch (CEMP-RT).

c. The specific application of and adherence to these guidelines must be tailored to each project as a function of the contaminants of concern; local geohydrologic setting; geotechnical judgment; available resources; applicable regulatory requirements; policy and guidance; public concerns; and project mission.

1-3. References

Appendix A contains a list of those publications referenced by and relevant to this manual.

1-4. Terminology

a. General. As in any relatively new field using the principles, terminology, and personnel of several other fields, there is a certain lack of communication over the language used to express data and mechanisms within this new field. The situation is further compounded by alternative methods, both traditional and innovative, to complete actual projects. The additional requirements for permits, licenses, and other federal and state regulatory procedures, and the potential for litigation, add to the HTRW site complexities.

b. Corps situation.

(1) Within USACE, a given HTRW project may be performed totally in-house, partially in-house, or by one or more contractors/AE's (either independently reporting to the Corps or through a system of prime- and subcontracting). One Corps office may broker the work of another who in turn contracts the effort. In some cases, one Corps district may design a project and award the contract while a second district supervises construction.

(2) Providing program level technical guidance in this administrative situation requires the guidance to be specific, while allowing any field activity to adapt the guidance to its needs. The intent is to foster the defense of variances, not the defense of recommended methods and procedures. This approach is warranted to provide the Corps with compatibility and continuity of HTRW investigations while allowing functional flexibility. With this in mind, the following three terms are introduced: the *field activity* (FA); the *field drilling organization* (FDO); and the *drilling and well installation plan.* These terms are defined in paragraphs 1-4*c*(2), (3), and (1), respectively. Generically, these terms refer to a client-contractor-contract relationship. This relationship can be applied to both in-house and contracted efforts, thereby providing consistency for the geotechnical portion of the Corps HTRW involvements.

c. Definitions (alphabetically arranged). These definitions are intended to guide the reader through the use of this manual. While other terms with equivalent definitions may be familiar to some readers, the terminology as defined here provides a common basis for the **CONSISTENT** understanding by **ALL** readers.

(1) Field Sampling Plan (FSP). The FSP is contained within the Sampling and Analysis Plan (SAP), and describes the drilling and well installation plan. The SAP and FSP requirements are outlined in EM 200-1-3. The FSP is approved by the FA or FDO before field activities begin. The plan specifies the particulars of the field effort; for example: borehole/well/sample locations, depths, equipment, materials, procedures and alternatives, quality control measures, and other topics required by the responsible FA. Implementation is by the FDO.

(2) Field activity (FA). That Corps element minimally headed by a Commander or Director; e.g., district, laboratory, or agency, assigned or otherwise acquiring the responsibility to administer a contract, agreement, or in-house Corps procedure to research, investigate, design, and/or construct a project involving hazardous and/or toxic wastes.

(3) Field drilling organization (FDO). That office within the Corps or contracted by the Corps responsible for execution of the drilling plan. In a contracted arrangement, the prime contractor is regarded as the FDO. Subcontractors, even though they may physically perform the field work, are the responsibility of the prime contractor, whom the Corps holds contractually accountable.

(4) Geotechnical data quality management (GDQM). The development and application of those policies and procedures required to obtain and utilize accurate and representative geotechnical information throughout the entire HTRW project cycle, from predesign investigations to postconstruction monitoring.

(5) Hazardous, toxic, and radioactive waste (HTRW). A USACE idiom referring to substances which because of their properties, occurrence, or concentration, may potentially pose a threat to human health and welfare, or to the environment. This includes materials defined by federal regulations as hazardous waste, hazardous substances, and pollutants.

(6) Monitoring well. A monitoring well is a device designed and constructed for the acquisition of groundwater samples that are representative of the chemical quality of the aquifer adjacent to the screened interval, unbiased by the well materials and installation process; and which, if so designed, provides access to measure potentiometric head across the screened interval.

(7) Redevelopment/well rehabilitation. A procedure which restores the original or near original pumping capacity to an existing well by the removal of sediment, precipitation, flocculent, surface run-in, or other built-up materials from within that well.

(8) Screened interval. That portion of a well which is directly open to the host environment/aquifer by way of openings in the well screen.

(9) Site safety and health plan (SSHP). A project-unique document approved by the responsible FA for FDO compliance. The plan includes the identification of hazardous substances present, recommended action upon encountering those substances, project/site safety requirements, organizational safety responsibilities, and the identification of supporting health and safety activities.

(10) Well development. A procedure which locally improves or restores the aquifer's hydraulic conductivity, well capacity, and removes well drilling fluids, muds, cuttings, mobile particulates, and entrapped gases from within and adjacent to a newly installed well.

d. Acronyms. Appendix B contains a list of the abbreviations used in this manual.

1-5. Background

a. EM 1110-1-4000. As a GDQM mechanism, this manual provides guidance for collection and documentation of geotechnical information. Site-specific deviations should be described and supported in the drilling and well installation plan.

(1) Technical understanding and evaluation of HTRW studies involve an appreciation of the interactions among many fields including geology, hydrology, geotechnical engineering, and chemistry. This scenario is complicated by the trace (low parts per billion) levels of regulated chemical species that are detectable in the environment and which, when detected or suspected, trigger intricate and costly response actions. Slight deviations from prescribed drilling, well installation, sampling, or analytical procedures may bias or invalidate the reported concentrations. This sensitivity requires that procedures be relevant, standardized, documented, understood, and followed. Despite these procedures, the normal heterogeneity and anisotropy of natural field occurrences are, in themselves, frequently sufficient to confuse the appropriate interpretation of the

gathered field data.

(2) The specific content of this manual will be periodically updated based upon reader suggestions, lessons learned, technological advances, and Corps needs. Issues of significant concern will be disseminated Corpswide in a more expeditious manner.

(3) Not all geotechnical personnel will agree on every practice advocated herein. Any such variations should be over a matter of degree, not substance. If the reader perceives a technical difficulty in any of this manual's contents, the reader is requested to contact the proponent.

b. Proponency. The technical proponents for this manual are the Policy and Technology Branch, Environmental Division, Directorate of Military Programs (CEMP-R), and the Geotechnical and Materials Branch, Engineering Division, Directorate of Civil Works (CECW-EG), Headquarters, U.S. Army Corps of Engineers. All comments and suggestions should be directed to HQUSACE, CEMP-R, 20 Massachusetts Avenue, N.W., Washington, D.C. 20314-1000.

Chapter 2
Boreholes and Wells: Site Reconnaissance, Locations, Quantities, and Designations

2-1. Site Reconnaissance

Site visits are suggested for project geotechnical personnel as early as practical in the planning for any subsurface exploration. The purpose of this reconnaissance is to evaluate physical site conditions and logistical support availability. Particular items of interest would include geologic and geographic settings, site access, proximal utilities, service areas, sample shipment facilities, and potential hazards. Application of this knowledge will contribute to enhancing the technical approach and cost realism for subsequent project development.

2-2. Locations and Quantities

The locations and quantities of boreholes and wells should be selected to effectively ascertain desired geologic, hydrologic, and/or chemical parameters. The number of borings or wells specified in the drilling plan should not be altered without coordination with the FA. The drilling and well installation plan should permit relocations when necessitated by proximal utilities or drilling difficulties. The criteria for selection of the new location(s) should be included as a portion of the drilling plan and should indicate when coordination would be required with the FA.

2-3. Designations

Borehole and well designations (identification numbers) should not be unilaterally changed in the field or in a centralized computer database without prior approval of the installing Corps organization or non-Corps agency. After receiving approval, the requesting FA should physically renumber those sites where a designation is posted in the field. Temporary conversions not involving the alteration of either field markings or a centralized database may be done for reporting purposes without approval of the installing organization or agency. Such temporary changes may be necessary, for instance, if the data entry format of a given computer system is not compatible with the characters in the existing well designation. A conversion table should be included in the final report to document any permanent *or* temporary boring/well designation changes.

Chapter 3
Drilling Operations

3-1. Physical Security

The FDO should comply with all security policies at the project site. The FDO is responsible for securing its own equipment. The FDO should address any special situations in the drilling plan.

3-2. Drilling Safety and Underground Utility Detection

When drilling in areas of known or suspected hazardous materials, appropriate health and safety precautions should be implemented. Guidance adaptable for drilling activities is available in Occupational Safety and Health Administration (OSHA) documents (particularly, 29 CFR 1910.120 and 29 CFR 1926), ER 385-1-92, and EM 385-1-1. The FDO should determine all applicable regulations, requirements, and permits with regard to drilling safety and underground utility detection. These items should be included in the safety plan. The safety plan should be approved by the FA prior to any drilling.

3-3. Permits, Licenses, Professional Registration, and Rights-of-Entry

The FA should be responsible for identifying all applicable permits, licenses, professional registration, rights-of-entry, and applicable state and local regulatory procedures for drilling, well installation, well decommissioning/ abandonment, and topographic surveying (to include any requirements for the submission of well logs, samples, etc.). Acquisition and submission of these items to state or local authorities should be coordinated between the FA and FDO, with the responsibilities of each specified in the drilling plan. The need for any rights-of-entry should be specified in the drilling plan along with the organization(s) responsible for their acquisition.

3-4. Site Geologist

A "site geologist" (defined as an earth science or engineering professional with a college degree in geology, civil engineering, or related field; experienced in HTRW projects, soil and rock logging, and monitoring well installation), should be present at each operating drill rig. This geologist should be responsible for logging; acquisitioning (and possibly shipment) of samples; monitoring of drilling operations; recording of water losses/gains and groundwater data; preparing the boring logs and well diagrams; and recording the well installation and decommissioning procedures conducted with that rig. Each site geologist should be responsible for only one operating rig. The geologist should have onsite sufficient tools, forms, and professional equipment in operable condition to efficiently perform the duties as outlined in this manual and other relevant project documents. Items in the possession of each site geologist should include, as a minimum, a copy of this manual, a copy of the approved drilling and well installation plan, log forms, the approved safety plan, a 10-power (minimum) hand lens, and a measuring tape (weighted with stainless steel or chemically stable, nonmetallic material) long enough to measure the deepest boring/well within the project, heavy enough to reach that depth, and small enough to readily fit within the appropriate annulus or opening. Each site geologist should also have onsite a water-level measuring device (preferably electrical), pH and electric conductivity meters, a turbidimeter, a thermometer, an instrument for measuring dissolved oxygen, and materials necessary to prepare the samples for storage or shipment. At some sites, the geologist may be also responsible for monitoring gases during drilling. If so, the geologist should have the necessary instruments and be proficient in their use and calibration.

3-5. Equipment

a. Condition. All drilling, sampling, and supporting equipment brought to a site should be in operable condition and free of leaks in the hydraulic, lubrication, fuel, and other fluid systems where fluid leakage would or could be detrimental to the project effort. All switches (to include safety switches), gages, and other electrical, mechanical, pneumatic, and hydraulic systems should be in a safe and operable condition prior to arrival onsite.

b. Cleaning. All drilling equipment should be cleaned with steam or pressurized hot water before arriving at the project installation/site. After arrival but prior to project commencement, all drilling equipment including rigs, support vehicles, water tanks (inside and out), augers, drill casings, rods, samplers, tools, recirculation tanks, etc., should be cleaned with steam or pressurized hot water using approved water (see paragraph 3-9*b*) at the installation decontamination point. Guidance for decontamination of field equipment may be found in ASTM D 5088. Samplers and other equipment, such as water level indicators, oil/water interface probes, etc. may require additional decontamination steps. A similar cleaning should also occur between each boring/well site. After the onsite cleaning, only the equipment used or soiled at a particular boring or well should need to be recleaned between sites. Unless circumstances require otherwise, water tank interiors may not need to be cleaned between each boring/well at a given project. Prior to use, all casings, augers, recirculation and water tanks, etc., should be devoid both inside and out of any asphaltic, bituminous, or other encrusting or coating materials, grease, grout, soil, etc. Paint, applied by the equipment manufacturer, may not have to be removed from

drilling equipment, depending upon the paint composition and its contact with the environment and contaminants of concern. All equipment should be decontaminated before it is removed from the project site. If drilling requires telescoping casing because of differing levels of contamination in subsurface strata, then decontamination may be necessary before setting each string of smaller casing and before drilling beyond any casing. To the extent practical, all cleaning should be performed in a single remote area that is surficially crossgradient or downgradient from any site to be sampled. Waste solids and water from the cleaning/decontamination process should be properly collected and disposed. This may require that cleaning be conducted on a concrete pad or other surface from which the waste materials may be collected. Guidance for decontamination of field equipment used at low level radioactive waste sites may be found in ASTM D 5608.

3-6. Drilling Methods

a. Objective. The objective of selecting a drilling method for monitor well installation is to use that technique which

(1) Provides representative data and samples.

(2) Eliminates or minimizes the potential for subsurface contamination and/or cross-contamination.

(3) Minimizes drilling costs.

b. Methods. Table 3-1 presents types of drilling methods. Detailed descriptions of different drilling methods may be found in EPA/600/4-89/034, EPA/625/R-93/003a, USGS WRI Report 96-4233, USGS TWRI Book 2 Chapter F1, ASTM D 6286, Driscoll (1986), and U.S. Army FM 5-484. Where possible, ASTM drilling method-specific guides are referenced with the drilling methods listed below.

(1) Hollow stem augers. Method references: ASTM D 5784 and EPA/600/4-89/034.

(2) Cable tool/churn drill. Method reference: ASTM D 5875.

(3) Water/mud rotary. Method references: ASTM D 5781, D 5783, and D 5876.

(4) Air/pneumatic rotary methods. Method reference: D 5782.

(5) Sonic/vibratory. Method reference: EPA/625/R-94/003.

(6) Direct Push. Method references: ASTM Standard Guides D 6001 and D 6282, and EPA/510/B-97/001.

c. Special concerns.

(1) Dry methods.

(a) Hollow stem augers are technically advantageous in most situations because of their "dry" method of drilling. A dry drilling method is preferred for HTRW work. Dry methods advance a boring using purely mechanical means without the aid of an aqueous or pneumatic drilling "fluid" for cuttings removal, bit cooling, or borehole stabilization. In this way, the chemical interface with the subsurface is minimized, though not eliminated. Local aeration of the borehole wall, for example, may occur simply by the removal of compacted or confining soil or rock.

(b) Vibratory, or sonic drilling, employs the use of high-frequency mechanical vibration to take continuous core samples of overburden soils and most hard rock. A sonic drill rig uses an oscillator, or head, with eccentric weights driven by hydraulic motors, to generate high sinusoidal force in a rotating drill pipe. The frequency of vibration of the drill bit or core barrel can be varied to allow optimum penetration of subsurface materials. Sonic drilling penetrates a formation by displacement, shearing, or fracturing. Displacement occurs by fluidizing the soil particles (sands and light gravels) and causing them to move either into the formation or into the center of the drill pipe. Shearing occurs in dense silts, clays, and shales, if the axial oscillations of the drill pipe overcomes the elastic nature of the material. The penetration of cobbles, boulders, and rock is caused by fracturing of the material by the inertial moment of the drill bit. Although, rock drilling and sampling requires the addition of water or air to remove drill cuttings, the volume of drill cuttings generated during sonic drilling is usually much less than those generated from some other drilling methods. Drilling through unconsolidated material can be done in the dry, without the use of drilling fluids such as air or water-based fluids and additivies. Overall, the sonic drilling method can also offer the advantages of obtaining relatively undisturbed soil and rock samples at higher drilling rates than conventional methods, with high percentage of core recovery, and produces less investigation-derived waste.

TABLE 3-1

DRILLING METHODS

Method	Drilling Principle	Depth Limitation m (Ft.)	Advantages	Disadvantages
Direct-Push	Advancing a sampling device into the subsurface by applying static pressure, impacts, or vibration or any combination thereof to the above ground portion of the sampler extensions until the sampler has been advanced its full length into the desired soil strata.	30 (100)	Avoids use of drilling fluids and lubricants during drilling. Equipment highly mobile. Disturbance of geochemical conditions during installation is minimized. Drilling and well screen installation is fast, considerably less labor intensive. Does not produce drill cuttings, reduction of IDW.	Limited to fairly soft materials such as clay, silt, sand, and gravel. Compact, gravelly materials may be hard to penetrate. Small diameter well screen may be hard to develop. Screen may become clogged if thick clays are penetrated. The small diameter drive pipe generally precludes conventional borehole geophysical logging. The drive points yield relatively low rates of water.
Auger, Hollow- and Solid-Stem	Successive 1.5m (5-ft) flights of spiral-shaped drill stem are rotated into the ground to create a hole. Cuttings are brought to the surface by the turning action of the auger.	45 (150)	Fairly inexpensive. Fairly simple and moderately fast operation. Small rigs can get to difficult-to-reach areas. Quick setup time. Can quickly construct shallow wells in firm, noncavey materials. No drilling fluid or lubricants required. Use of hollow-stem augers greatly facilitates collection of split-spoon samples, continuous sampling possible. Small-diameter wells can be built inside hollow-stem flights when geologic materials are cavey.	Depth of penetration limited, especially in cavey materials. Cannot be used in rock or well-cemented formations. Difficult to drill in cobbles or boulders. Log of well is difficult to interpret without collection of split spoons due to the lag time for cuttings to reach ground surface. Soil samples returned by auger flight are disturbed making it difficult to determine the precise depth from which the sample came. Vertical leakage of water through borehole during drilling is likely to occur. Solid-stem limited to fine-grained, unconsolidated materials that will not collapse when unsupported. Borehole wall can be smeared by previosly-drilled clay. With hollow-stem flights, heaving sand can present a problem. May need to add water down-auger to control heaving or wash materials from auger before completing well.
Jetting	Washing action of water forced out of the bottom of the drill rod clears hole to allow penetration. Cuttings brought to surface by water flowing up the outside of the drill rod.	15 (50)	Relatively fast and inexpensive. Driller often not needed for shallow holes. In firm, noncavey deposits where hole will stand open, well construction fairly simple. Minimul equipment required. Equipment highly mobile.	Somewhat slow with increasing depth. Limited to drilling relatively shallow depth, small diameter boreholes. Extremely difficult to use in very coarse materials, i.e., cobbles and boulders. Large quantities of water required during drilling process. A water supply is needed that is under enough pressure to penetrate the geologic materials present. Use of water can affect groundwater quality in aquifer. Difficult-to-interpret sequence of geologic materials from cuttings. Presence of gravel or larger materials can limit drilling. Borehole can collapse before setting monitoring well if borehole uncased.

TABLE 3-1

DRILLING METHODS

Method	Drilling Principle	Depth Limitation m (Ft.)	Advantages	Disadvantages
Cable-tool (percussion)	Hole created by dropping a heavy "string" of drill tools into well bore, crushing materials at bottom. Cuttings are removed occasionally by bailer. Generally, casing is driven just ahead of the bottom of the hole; a hole greater than 6 inches in diameter is usually made.	300+ (1,000 +)	Can be used in rock formations as well as unconsolidated formations. Can drill through cobbles and boulders and highly cavernous or fractured rock. Fairly accurate logs can be prepared from cuttings if collected often enough. Driving a casing ahead of hole minimizes cross-contamination by vertical leakage of formation waters and maintains borehole stability. Recovery of borehole fluid samples excellent throughout the entire depth of the borehole. Excellent method for detecting thin water-bearing zones. Excellent method for estimating yield of water-bearing zones. Excellent method for drilling in soil and rock where lost circulation of drilling fluid is possible. Core samples can be easily obtained. Excellent for development of a well.	The potential for cross-contaminated samples is very high. Decontamination can be difficult. Heavy steel drive pipe used to keep hole open and drilling "tools" can limit accessibility. Cannot run some geophysical logs due to presence of drive pipe. Relatively slow drilling method. Heavier wall, larger diameter casing than that used for other drilling methods normally used. Temporary casing can cause problems with emplacement of effective filter pack and grout seal. Heaving of unconsolidated sediment into bottom of casing can be a problem.
Mud Rotary	Rotating bit breaks formation; cuttings are brought to the surface by a circulating fluid (mud). Mud is forced down the interior of the drill stem, out the bit, and up the annulus between the drill stem and hole wall. Cuttings are removed by settling in a "mud pit" at the ground surface and the mud is circulated back down the drill stem.	1,500+ (5,000 +)	Drilling is fairly quick in all types of geologic materials, hard and soft. Borehole will stay open from formation of a mud wall on sides of borehole by the circulating drilling mud. Eases geophysical logging and well construction. Geologic cores can be collected. Can use casing-advancement drilling method. Borehole can readily be gravel packed and grouted. Virtually unlimited depths possible.	Expensive, requires experienced driller and fair amount of peripheral equipment. Completed well may be difficult to develop, especially small diameter wells, because of mud or filter-cake on wall of borehole. Lubricants used during drilling can contaminate the borehole fluid and soil/rock samples. Geologic logging by visual inspection of cuttings is fair due to presence of drilling mud. Beds of sand, gravel, or clay may be missed. Location of water-bearing zones during drilling can be difficult to detect. Drilling fluid circulation is often lost or difficult to maintain in fractured rock, root zones, or in gravels and cobbles. Difficult drilling in boulders and cobbles. Presence of drilling mud can contaminate water samples, especially the organic, biodegradable muds. Overburden casing usually required. Circulation of drilling fluid through a contaminated zone can create a hazard at the ground surface with the mud pit and cross-contaminate clean zones during circulation.

TABLE 3-1

DRILLING METHODS

Method	Drilling Principle	Depth Limitation m (Ft.)	Advantages	Disadvantages
Reverse Rotary	Similar to hydraulic rotary method except the drilling fluid is circulated down the borehole outside the drill stem and is pumped up the inside, just the reverse of the normal rotary method. Water is used as the drilling fluid, rather than a mud, and the hole is kept open by the hydrostatic pressure of the water standing in the borehole.	1,500+ (5,000 +)	Drilling readily accomplished in soils and most hard rock. Drilling is relatively fast and for drilling large diameter boreholes. Borehole is accessible for geophysical logging prior to installation of well. Creates a very "clean" hole, not dirtied with drilling mud. Large diameter of borehole permits relatively easy installation of monitoring well. Can be used in all geologic formations. Very deep penetrations possible. Split-spoon sampling possible.	Drilling through cobbles and boulders may be difficult. Use of drilling fluids, polymeric additives, and lubricants can affect the borehole chemistry. A large water supply is needed to maintain hydrostatic pressure in deep holes and when highly conductive formations are encountered. Expensive--experienced driller and much peripheral equipment required. Hole diameters are usually large, commonly 18 inches or greater. Cross-contamination from circulating water likely. Geologic samples brought to surface are generally poor; circulating water will "wash" finer materials from sample.
Air Rotary	Very similar to hydraulic rotary, the main difference is that air is used as the primary drilling fluid as opposed to mud or water.	1,500+ (5,000 +)	Can be used in all geologic formations; most successful in highly fractured environments. Useful at most any depth. Drilling in rock and soil is relatively fast. Can use casing-advancement method. Drilling mud or water not required. Borehole is accessible for geophysical logging prior to monitoring well installation. Well development relatively easy.	Relatively expensive. Cross-contamination from vertical communication possible. Air will be mixed with the water in the hole and blown from the hole, potentially creating unwanted reactions with contaminants; may affect "representative" samples. Air, cuttings and water blown from the hole can pose a hazard to crew and surrounding environment if toxic compounds encountered. Compressor discharge air may contain hydrocarbons. Organic foam additives to aid cuttings removal may contaminate samples. Overburden casing usually required.
Sonic (vibratory)	Employs the use of high-frequency mechanical vibration to take continuous core samples of overburden soils and most hard rock.	150 (500)	Can obtain large diameter, continuous and relatively undisturbed cores of almost any soil material without the use of drilling fluids. Can drill through boulders, wood, concrete and other construction debris. Can drill and sample most softer rock with high percentage of core recovery. Drilling is faster than most other methods. Reduction of IDW.	Rock drilling requires the addition of water or air or both to remove drill cuttings. Extraction of casing can cause smearing of borehole wall with silt or clay. Extraction of casing can damage well screen. Equipment is not readily available and is expensive.

TABLE 3-1

DRILLING METHODS

Method	Drilling Principle	Depth Limitation m (Ft.)	Advantages	Disadvantages
Air-Percussion Rotary or Down-the-Hole (DTH) Hammer	Air rotary with a reciprocating hammer connected to the bit to fracture rock.	600 (2,000)	Very fast penetrations. Useful in all geologic formations. Only small amounts of water needed for dust and bit temperature control. Cross-contamination potential can be reduced by driving casing. Can use casing-advancement method. Well development relatively easy.	Relatively expensive. As with most hydraulic rotary methods, the rig is fairly heavy, limiting accessibility. Overburden casing usually required. Vertical mixing of water and air creates cross-contamination potential. Hazard posed to surface environment if toxic compounds encountered. DTH hammer drilling can cause hydraulic fracturing of borehole wall. The DTH hammer requires lubrication during drilling. Organic foam additives for cuttings removal may contaminate samples.

(c) Another dry method, known as the direct push method, involves sampling devices that are directly inserted into the soil to be sampled without drilling or borehole excavation. Direct push sampling also includes the use of the Site Characterization and Analysis Penetrometer System (SCAPS) which has contaminant screening capability in addition to indirect soil stratigraphy information (ASTM D 5778 and D 6067). Direct push sampling consists of advancing a sampling device into the subsurface by applying static pressure, impacts, or vibration or any combination thereof to the above ground portion of the sampler extensions until the sampler has been advanced its full length into the desired soil strata. Direct push methods may be used to collect both soil (ASTM D 6282) and water samples (ASTM D 6001). In some cases the method may combine water sampling and/or vapor sampling with soil sampling in the same investigation. The direct push sampling method is widely used as a preliminary site characterization tool for the initial field activity of a site investigation. Direct push sampling is an economical and efficient method for obtaining descrete soil and water samples without the expense of drilling and its related decontamination and waste cuttings disposal costs. This method may be especially advantageous at a radioactive site, where the reduction of IDW is of special importance. The equipment generally used in direct push sampling is small and relatively compact allowing for better mobility around the site and access to confined areas. The rapid sample gathering provided by direct push methods can be used to determine the chemical composition of the soils and ground water in the field in certain circumtances. This method may offer an immediate determination of the need for further monitoring points. It must be cautioned, however, that certain temporary well points installed by this method may not be allowed as permanent monitoring wells by some state and local regulations.

(2) Pneumatic methods. When air is used it should be detailed in the drilling plan, to include the following items:

(a) Situation favoring air usage.

(b) Air drilling method to be used.

(c) Expected subsurface contaminants, and how field personnel will be protected from any adverse effects caused by these contaminants in the returned air and particles blown from the borehole or well.

(d) The potential effects of air usage upon the chemical analyses of groundwater and soil (especially for volatile species) and the mitigation procedures to negate the detrimental aspects of these effects.

(e) The potential effects of air usage upon the physical, hydrological, and structural character of the surrounding soil and/or rock and the mitigation to address the negative aspects of these effects.

(f) Measures to be taken to reduce oil usage and to limit aquifer aeration.

(g) Specify the type of air compressor and compressor lubricating oil and require that sufficient samples of the initial reservoir (and any refill) oil be retained by the FDO, along with a record of oil loss (recorded on the boring log), for evaluation in the event of future problems. The oil sample(s) may be disposed of upon project completion.

(h) Require an air line oil filter and that the filter be changed per manufacturer's recommendation during operation with a record kept (on the boring log) of this maintenance. More frequent changes should be made if oil is visibly detected in the filtered air, as by an oil stain on clean, writing paper after directing the filtered air from a hose onto the paper "300 mm" ("a foot") away for "15 seconds." (While these numbers are arbitrary, they are provided as examples for FDO guidance and intra/interproject consistency.)

(i) Prohibit the use of any additive except approved water for dust control and cuttings removal.

(j) Detail the use of any downhole hammer/bit with emphasis upon those procedures to be taken to preclude residual groundwater sample contamination caused by the lubrication of the downhole equipment.

(k) Discuss the volume of air and pressure rating required for drilling and whether a downhole hammer, rotary bit, or both can be used. The air volume and pressure required should be adequate for the hole diameter, boring depth, available equipment, and site conditions.

(l) Detail the use of any bottled gas with emphasis on air composition, quality, quantity, method of bottling, and anticipated use.

(m) Air usage should be fully described in the boring log to include equipment description(s), manufacturer(s), model(s), air pressures used, frequency of oil filter change, and evaluation of the system performance, both design and actual.

(3) Aqueous methods.

(a) Aqueous drilling methods use a fluid, usually water, or a water and bentonite mix, for cuttings removal, bit cooling, and hole stabilization. For HTRW work, the use of these materials increases the potential to add a new contaminant or suite of contaminants to the subsurface environment adjacent to the boring. Even the removal of one or more volumes of water equal to that which was lost during drilling will not remove all of the lost fluid. In addition, the level of effort to be expended upon well development is directly tied to the amount of water loss during drilling: a minimum of three times the volume lost to be removed during development. Therefore, the less fluid loss, the less the development effort (time and cost).

(b) The situation is further complicated when bentonite is used. While bentonite tends to reduce the amount of drilling fluid loss, the residual bentonite remaining around the boring after development may provide sufficient sorptive material to modify local groundwater chemistry for some parameters (for example, metals).

3-7. Recirculation Tanks and Sumps

If possible, only portable recirculation tanks should be used for mud/water rotary operations and similar functions. The use of dug sumps or pits (lined) should be used only if necessary, as when the volume necessary to handle problem holes that encounter running sand or gravel is greater than can be handled by a portable tank. This is important in order to minimize cross-contamination and to enhance both personal safety and work area restoration.

3-8. Materials

a. Bentonite. Bentonite is the only drilling fluid additive that is typically allowed under normal circumstances. This includes any form of bentonite (powders, granules, or pellets) intended for drilling mud, grout, seals, etc. Organic additives should not be used. Exception might be made for some high yield bentonites, to which the manufacturer has added a small quantity of polymer. The use of any bentonite should be discussed in the drilling plan and approved by the FA. Bentonite should only be used if absolutely necessary to ensure that the borehole will not collapse or to improve cuttings removal. The following data should be included in the drilling plan and submitted along with a sample of the material for approval:

(1) Brand name(s).

(2) Manufacturer(s).

(3) Manufacturer's address and telephone number(s).

(4) Product description(s) from package label(s) or manufacturer's brochure(s), to include any polymer or other additives.

(5) Intended use(s) for this product.

(6) Potential effects on chemical analyses of subsequent samples.

b. Water.

(1) To the extent practical, the use of drilling water should be held to a minimum at HTRW sites. When water usage is deemed necessary, the source of any water used in drilling, grouting, sealing, filter placement, well installation, well decommissioning/abandonment, equipment washing, etc. should be approved by the FA prior to arrival of the drilling equipment onsite and specified in the drilling plan. Desirable characteristics for the source include:

(a) An uncontaminated aquifer origin;

(b) Wellhead upgradient of potential contaminant sources;

(c) Be free of survey-related contaminants by virtue of pretesting (sampling and analysis) by the FDO using a laboratory validated by USACE for those contaminants using methods within that validation, and knowledge of the water-chemistry is the most important factor in water approval;

(d) The water is untreated and unfiltered;

(e) The tap has accessibility and capacity compatible with project schedules and equipment; and

(f) Only one designated tap for access.

(2) Surface water bodies should not be used, if at all practical.

(3) If a suitable source exists onsite, that source should be used. If no onsite water is available, the FDO should both locate a potential source and submit the following data in writing to the FA for approval prior to the arrival of any drilling equipment onsite. A suggested format is given in Figure 3-1.

(a) Owner/address/telephone number.

(b) Location of tap/address.

(c) Type of source (well, pond, river, etc.). If a well, specify static water level (depth), date measured, well depth, and aquifer description.

(d) Type of any treatment and filtration prior to tap (e.g., none, chlorination, fluoridation, softening, etc.).

(e) Time of access (e.g., 24 hours per day, 7 days per week, etc.).

(f) Cost per liter (gallon) charged by owner/operator.

(g) Results and dates of all available chemical analyses over past 2 years. Include the name(s) and addresses of the analytical laboratory(s).

(h) Results and date(s) of chemical analysis for project contaminants by a laboratory validated by USACE for those contaminants.

(4) The FDO should have the responsibility to procure, transport, and store the water required for project needs in a manner to avoid the chemical contamination or degradation of the water once obtained. The FDO also should be responsible for any heating, thermal insulation, or agitation of the water to maintain the water as a fluid for its intended uses.

c. Grout.

(1) Cement. Cement grout, when used in monitoring well construction or borehole/well decommissioning, should be composed of Type I Portland cement (ASTM C 150), bentonite (2-5% dry bentonite per 42.6 kg (94 lb) sack of dry cement) and a maximum of 23 to 26 L (6-7 gal) of approved noncontaminated-water per sack of cement. The addition of bentonite to the cement admixture will aid in reducing shrinkage and provide plasticity. Note that the maximum amount of dry bentonite allowed here varies from the 10 percent allowable in ASTM D 5092. The amount of water per sack of cement required for a pumpable mix will vary with the amount of bentonite used. The amount of water used should be kept to a minimum. When a sulfate resistant grout is needed, Types II or V cement should be used instead of Type I. Neither additives nor borehole cuttings should be mixed with the grout. The use of air-entrained cement should be avoided to negate potential analytical interference in groundwater samples by the entraining additives.

(2) Bentonite. Bentonite grout is a specially designed product, which is differentiated from a drilling fluid by its high solids content, absence of cement and its pumpability. A typical high solids bentonite grout will have a solids content between 20 and 30 percent by weight of water and remain pumpable. By contrast, a typical low solids bentonite, as used in a drilling fluid, contains a solids content between 3 and 6 percent by weight of water. The advantages of using bentonite grout include (Oliver 1997) :

- Bentonite grouts, when hydrated, exert constant pressure against the walls of the annulus, leaving no room for contaminants to travel in the well.
- Bentonite grouts are more flexible and do not shrink and crack when hydrated, creating a low permeability seal.
- Placement using bentonite grouts is much easier because more time is allowed for setting.
- Bentonite high solids grouts require less material handling than cement.
- Bentonite grouts are chemically inert, which protects personal safety, equipment, and water quality.
- Bentonite grouts have no heat of hydration making them compatible with polyvinyl chloride (PVC) casing.
- Wells constructed with bentonite grouts can be easily reconstructed if necessary.
- Cleanup of bentonite grouts is much easier than with cement grouts.

Situations where bentonite grout should not be used are when additional structural strength is needed or when excessive chlorides or other contaminants such as alcohols or ketones are present. Under artesian conditions the bentonite does not have the solids content found in a cement-bentonite grout and will not settle where a strong uplift is present. Where structural support is needed, bentonite grout does not set up and harden

like a cement and will not supply the support a cement-bentonite grout will provide (Colangelo 1988).

(3) Equipment. All grout materials should be combined in an aboveground rigid container or mixer and mechanically (not manually) blended onsite to produce a thick, lump-free mixture throughout the mixing vessel. The mixed grout should be recirculated through the grout pump prior to placement. Grout should be placed using a grout pump and pipe/tremie. The grout pipe should be of rigid construction for vertical control of pipe placement. Drill rods, rigid polyvinyl chloride (PVC) or metal pipes are suggested stock for tremies. If hoses or flexible plastics must be used, they may have to be fitted with a length of steel pipe at the downhole end to keep the flexible material from curling and embedding itself into the borehole wall. This is especially true in cold weather when the coiled material resists straightening. Grout pipes should have **SIDE** discharge holes, **NOT** end discharge. The side discharge will help to maintain the integrity of the underlying material (especially the bentonite seal).

d. Granular filter pack.

(1) Proper design of hydraulically efficient monitoring wells can be accomplished by designing the well in such a way that either the natural coarse-grained formation materials or artificially introduced coarse-grained materials, in conjunction with appropriately sized intake openings, retain the fine materials outside the well while permitting water to enter. Thus, there are two types of wells and well intake designs for wells installed in unconsolidated or poorly-consolidated geologic materials: natural developed wells and wells with an artificially introduced filter pack. In both types of wells, the objective of a filter pack is to increase the effective diameter of the well and to surround the well intake with an envelope of relatively coarse material of greater permeability than the natural formation material (EPA/600/4-89/034). The decision to design the well using the natural formation as the filter pack should include consideration that the natural formation material may slough in high enough above the top of the well screen to leave insufficient room for the bentonite seal. All granular filters should be approved by the FA prior to drilling and should be discussed in the drilling plan. Discussions should include composition, source (natural formation or artificial), placement, and gradation. The FDO should either prescribe the gradation of the filter pack in the field sampling plan (FSP) or detail that it will be determined after a sieve analysis of the stratum in which the screen is to be set has been performed. If the actual gradation is to be determined during drilling, more than one filter pack gradation should be on hand so that well installation will not be unnecessarily delayed. A 0.5 L (one-pint) representative sample for visual familiarization of each proposed granular filter pack, accompanied by the data below, should be submitted by the FDO to the FA for approval prior to drilling. Each sample should be described, in writing (see Figure 3-2 for submittal format), in terms of:

(a) Lithology;

(b) Grain size distribution;

(c) Brand name, if any;

(d) Source, both manufacturing company and location of pit or quarry of origin for artificial filter packs;

(e) Processing method for artificial filter packs, e.g., pit run, screened and unwashed, screened and washed with water from well/river/pond, etc.; and

(f) Slot size of intended screen.

(2) Granular filter packs should be visually clean (as seen through a 10-power hand lens), free of material that would pass through a No. 200 (75 μm [0.0029 in.]) sieve, inert, siliceous, composed of rounded grains, and of appropriate size for the well screen and host environment. Organic matter, soft, friable, thin, or enlongated particles are not permissible. A chemical analysis, including analytes of project concern, may be advisable in some circumstances. However, the reproducibility of that result should be evaluated against the spatial and temporal variability of the aggregate source and processing methods. The filter material should be packaged in bags by the supplier and therein delivered to the site.

e. Well screens, casings, and fittings.

(1) Typically, only PVC, polytetrafluoroethylene (PTFE), and/or stainless steel should be used. All PVC screens, casings, and fittings should conform to National Sanitation Foundation (NSF) Standard 14 for potable water usage or ASTM Standard Specification F 480 and bear the appropriate rating logo. If the FDO uses a screen and/or casing manufacturer or supplier who removes or does not apply this logo, the FDO should

WATER APPROVAL

Project for Intended Use:

1. Water source:
   Owner:
   Address:
   Telephone Number:

2. Water tap location:
   Operator:
   Address:

3. Type of source:
   Aquifer:
   Well depth:
   Static water level from ground surface:
   Date measured;

4. Type of treatment prior to tap:

5. Type of access:

6. Cost per liter (gallon) charged by Owner/Operator:

7. Attach results and dates of chemical analyses for past 2 years. Include name(s) and address(s) of analytical laboratory(s).

8. Attach results and dates of chemical analyses for project analytes by the laboratory certified by, or in the process of being certified.

SUBMITTED BY:

Company:

Person:

Telephone Number:

Date:

FOA APPROVAL (A)/DISAPPROVAL (D) (Check one)

Project Officer: A D

Project Geologist/Date: A D

Figure 3-1. Suggested format for use in obtaining water approval

include in the drilling plan a written statement from the manufacturer/supplier (and endorsed by the FDO) that the screens and/or casing have been appropriately rated by NSF or ASTM. Specific materials should be specified in the drilling plan approved by the FA. All materials should be as chemically inert as technically practical with respect to the site environment.

(2) All well screens should be commercially fabricated, slotted or continuously wound, and have an inside diameter (ID) equal to or greater than the ID of the well casing. An exception may be needed in the case of continuously wound screens because their supporting rods may reduce the full ID. If the monitoring well is to be subject to aquifer testing (slug test or pump test), a continuous wound screen should be used. Stainless steel screens may be used with PVC or PTFE well casing. No fitting should restrict the ID of the joined casing and/or screen. All screens, casings, and fittings should be new.

(3) Couplings within the casing and between the casing and screen should be compatibly threaded. Thermal or solvent welded couplings on plastic pipe should not be used. This caution also applies to threaded or slip-joint couplings thermally welded to the casing by the manufacturer or in the field. Several thermally welded joints have been known to break during well installation on a single project. The avoidance should remain until the functional integrity of thermal welds has been substantiated.

(4) Pop rivets, or screws should not be used on monitor wells. Particular problems with their use include anomalous analytical results, restriction of the well ID, and a loss of well integrity at the point of application.

f. Well caps and centralizers.

(1) The tops of all well casings should be telescopically covered with a slip-joint-type cap. Each cap should be composed of PVC, PTFE, or stainless steel. Each cap should be constructed to preclude binding to the well casing due to tightness of fit, unclean surface, or frost, and secure enough to preclude debris and insects from entering the well. Caps and risers may be threaded. However, sufficient annular space should be allowed between the well and protective casing to enable one to thaw any frosted shut caps. Caps should be vented, or loose enough to allow equilibration between hydrostatic and atmospheric pressures. Special cap (and riser) designs should be provided by the FA or FDO for wells in floodplains and those instances where the top of the well may be below grade, e.g., in roadways and parking lots.

(2) The use of well centralizers should be considered for wells deeper than 6 m (20 ft). When used, they should be of PVC, PTFE, or stainless steel and attached to the casing at regular intervals by means of stainless steel fasteners or strapping. Centralizers should not be attached to any portion of the well screen or bentonite seal. Centralizers should be oriented to allow for the unrestricted passage of the tremie pipe(s) used for filter pack and grout placement.

g. Well protection materials. Elements of well protection are intended to protect the monitoring well from physical damage, to prevent erosion and/or ponding in the immediate vicinity of the monitoring well, and to enhance the validity of the water samples.

(1) The potential for physical damage is lessened by the installation of padlocked, protective iron/steel casing over the monitoring well and iron/steel posts around the well. The casing and posts should be new. The protective casing diameter or minimum dimension should be 100 mm (4 in.) greater than the nominal diameter of the monitor well, and the nominal length should be 1.5 m (5 ft). The protective posts should be at least 80 mm (3 in.) in diameter and the top modified to preclude the entry of water. If extra protection is necessary, the protective posts can be filled with concrete. Nominal length of the posts should be 1.8 m (6 ft). Special circumstances necessitating different materials should be addressed in the drilling plan.

(2) Erosion and/or ponding in the immediate vicinity of the monitoring well may be prevented by assuring that the ground surface slopes away from the monitoring well protective casing and by the spreading of a 150 mm (6-in.) thick, 2.4 m (8-ft) diameter blanket of 19- to -75-mm (3/4- to 3-in.) gravel around the monitoring well.

(3) The validity of the water samples is enhanced by a locking cover on the protective casing. The cover should be hinged or telescoped but not threaded. Lubricants on protective covers should be avoided. Threaded covers tend to rust and/or freeze shut. Lubricants applied to the threads to reduce this closure tend to adhere to sampling personnel and their equipment. All locks on these covers should be opened by a single key and, if possible, should match any locks previously installed at the site(s), and be made of noncorrosive matrial, such as brass.

h. Glues and solvents. The use of glues and solvents in monitoring well installation should be prohibited.

i. Tracers. Tracers or dyes should not be used or otherwise introduced into borings, wells, grout, backfill, groundwater, or surface water unless specifically approved in the drilling plan. The drilling plan should describe any

GRANULAR FILTER PACK APPROVAL

Project for Intended Use:

1. Filter Material Brand Name:
2. Lithology:
3. Grain Size Distribution:
4. Source:

    Company that made product:

    Location of pit/quarry of origin:

5. Processing Method:
6. Slot Size of Intended Screen:

Submitted by:

Company:

Person:

Telephone:

Date:

FOA APPROVAL (A)/DISAPPROVAL (D)	(Check one)	
Project Officer Name/Date:	A	D
Project Geologist Name/Date:	A	D

Figure 3-2. Suggested format for obtaining approval for filter pack

approved usage; chemical, radiological, and/or biological composition of the substances; and potential effects upon subsequent chemical, radiological, or biological analyses of the injected media. Discussion should also be provided of the expected, post-injection visual appearance of the media into which the substances are to be introduced. The discussion should also include relevant Federal and state regulations and those agencies' opinions relative to the approved usage.

j. Lubricants. If lubrication is needed on the threads or couplings of downhole drilling equipment, it should be biodegradable and nontoxic. Vegetable oil/shortening or PTFE tape may be used. Additives containing lead or copper should not be used. The only lubricant recommended for monitoring well joints is PTFE tape. The use and type of lubricants should be included in the drilling plan and boring logs/well construction diagrams.

k. Hydraulic fluids. Any hydraulic or other fluids in the drilling rig, pumps, transmissions, or other field equipment/vehicles should **NOT** contain any polychlorinated biphenyls (PCBs).

l. Antifreeze. The use of any antifreeze (either a commercially available automotive variety or a local derivation) to prevent overnight water line freezing should require FA approval. If antifreeze is added to any pump, hose, etc., where contact with drilling fluid is possible, this antifreeze should be completely purged with approved water prior to the equipment's use in drilling, mud mixing, or any other part of the overall drilling operation. A sample of the clean (approved) water that has been circulated through the equipment after antifreeze removal should be retained for laboratory analysis. Only antifreeze without rust inhibitors and/or sealants should be considered. Antifreeze usage should be noted on the boring log, including the dates, reasons, quantities, composition, and brand names of antifreeze used. Antifreeze usage should be a last resort option. No antifreeze should be used in the drilling operation. Overnight storage in a heated garage may be a better option than spending time purging antifreeze and getting frozen equipment ready to operate.

m. Agents and additives. The use of any materials or substances other than those recommended herein for drilling, well installation, or development should be prohibited. Included in this suggested prohibition are lead shot, lead wool, burlap, dispersing agents (e.g., phosphates), acids, explosives, disinfectants, organic based drilling additives, metallic based lubricants, chlorinated and petroleum based solvents, adhesives, etc.

n. Summary. A materials usage summary, or MSDS should be provided of any drilling/well construction materials which potentially could have a bearing on subsequent interpretation of the analytical results. An example summary is provided at Figure 3-3.

3-9. Surface Runoff

Surface runoff, e.g., precipitation, wasted or spilled drilling fluid, and miscellaneous spills and leaks, should not enter any boring or well either during or after construction. To help avoid such entry, the use of starter casing, recirculation tanks, berms around the borehole, surficial bentonite packs, etc., is recommended.

3-10. Drilling Through Contaminated Zones

a. Many borings and wells are drilled in areas that are clean relative to the deeper zones of interest. However, circumstances do arise that require drilling where the overlying soils or shallow aquifer may be contaminated relative to the underlying environment. This situation may be addressed by the placement of, at least, double casing: an outer permanent (or temporary) casing sealed in place and cleared of all previous drill fluids prior to proceeding into the deeper, "cleaner" environment. In this procedure, the outer drill casing is set and sealed within an "impermeable" layer or at a level below which the underlying environment is thought to be cleaner than the overlying environment. The drilling fluids used to reach this point are appropriately discarded, replaced by a new or fresh supply. This system can be repeated, resulting in telescopic drill casing through which the final well casing is placed. These situations should be addressed on a case-by-case basis in the drilling plan.

b. Caution should be exercised to prevent further migration of contaminants via boreholes, especially dense non-aqueous phase liquid (DNAPL) migration. A recommended investigation strategy is to drill in expected DNAPL zones only after subsurface conditions have been characterized by drilling in surrounding DNAPL-free areas (the "outside-in" strategy). In DNAPL zones, drilling should generally be minimized and should be suspended when a potential trapping layer is first encountered. Drilling through DNAPL zones into deeper strategraphic units should be avoided. Also non-invasive methods, such as geophysical or geochemical surveys, can be useful at some sites to roughly define subsurface geologic or contaminant conditions (USEPA OSWER Directive 9283.1-06).

3-11. Soil Sampling

a. Intact samples. Unless otherwise specified in the drilling plan, intact soil samples for physical descriptions, retention, and physical analyses should be taken continuously and retained for the first 3 m (10 ft) and every 1.5 m (5 ft) or at each change of material, whichever occurs first, thereafter. Soil samples should be collected at intervals that are consistent with the goals of the project. These samples should be representative of their host environment. Borehole cuttings do not usually provide the desired information and, therefore, are not usually satisfactory. Sampling procedures should be detailed in the drilling plan. Additional guidance on soil sampling can be found in EM 200-1-3, EM 1110-1-1906 and ASTM Standard Guide D 6169.

b. Odors. At the detection of any anomalous odors (or vapor readings) from the boring or intact samples, drilling should cease for an evaluation of the odors and to determine the crew's safety. After the field safety representative completes this evaluation and implements any appropriate safety precautions as may be required in the site safety and health plan (SSHP), drilling may only then resume. If the odors or vapor readings are judged by the field personnel to be contaminant-related, intact soil samples should be continuously taken until the odors/readings are within background ranges. These samples should be retained and preserved in appropriate screw-capped sample jars for possible chemical analysis. With the resumption of background readings,

routine sampling should resume. Specific procedures should be detailed in the FSP and SSHP.

c. Volume. Representative soil samples of sufficient volume for physical testing from each sampled interval should be retained for future reference or appropriate analysis. Upon boring completion, the number of samples retained from that boring may be reduced, retaining at least representative samples of major units, key samples, and those for testing requirements. Minimum information on each sample container should include the project, depth below surface, and boring and sample number. All samples known or suspected to contain contaminants of concern should be so marked on both the sample container and boring log. No geotechnical data should appear on the container that is not specified on the boring log. Containers should be kept from becoming frozen. Soil samples known or suspected of being contaminated may have to be handled, stored, tested, and/or disposed of as hazardous waste. Storage, packaging, and shiping instructions for soil samples for physical testing should be prescribed in the drilling plan. USEPA has published additional guidance concerning the management of investigation-derived wastes (IDW) for Superfund projects (USEPA, EPA/540/G-91/009 and USEPA, OSWER Publication 9345.3-03FS) that should be incorporated into the drilling plan, as appropriate.

d. Physical testing. Physical soil testing is a function of the project. The drilling plan should detail specific testing guidance and requirements. The appropriate number of field samples selected for physical soil testing as well as sample retrieval locations should be determined by the project geotechnical personnel. Procedures and equipment for soil testing are described in the current EM 1110-2-1906 (or ASTM Standard Test Method D 2487). Downhole geophysical logging may reduce the need for sampling. Tested samples should be representative of the range and frequency of soil types encountered in the project area and should specifically include the screened interval of each completed well. In addition, samples should be obtained from borings that cover the geographic and geologic range within the project area. The FDO should select the particular samples. Samples selected for physical testing that are suspected to be contaminated should be labeled as such. Tests should include moisture content and those tests necessary to determine the soil classification as described in D 2487. Laboratory and summary sheets should be submitted to the FA after final test completion. The drilling and safety plans should address any contaminant-related safety precautions for the physical analysis of these samples. The FDO is responsible for communicating these concerns to the laboratory performing the soil testing. The testing laboratory is responsible for taking all the necessary health and safety precautions adequate to protect the laboratory personnel. Samples for physical analysis which are known or suspected to be contaminated should be tested only in a soils laboratory equipped and managed to process contaminated samples.

e. Soil samples for chemical analysis.

(1) Samples should be extracted from an as intact, minimally disturbed condition as technically practical. Once at the surface, the sampler should be opened, sample extracted, and bottled in as short a time as possible. Samples for volatile analysis should be bottled, and capped within a **VERY** short time (about 15 seconds from the time of opening the sampler). Each soil sample for volatile analysis should have minimal head space for representative analytical results.

(2) All sampling equipment that will contact the sample should be thoroughly decontaminated between samples. This can be accomplished by the use of a hot-water pressure washer or as follows:

(a) Scrub equipment with a low-sudsing, nonphosphate detergent in approved water.

(b) Rinse with approved water.

(c) When sampling for metals, rinse with 0.1 N nitric acid (4.2 mL of concentrated nitric acid added to 1,000 mL (33 fl oz) of water). (**CAUTION**: Add acid to water, never add water to concentrated acid.) Continue rinsing the sampling equipment now with distilled or deionized water. If the sampling equipment being used is made of stainless steel, the use of 0.1 N hydrochloric acid (rather than 0.1 N nitric acid) is preferred to avoid oxidation (rusting) of the stainless steel. The 0.1 N hydrochloric acid is prepared by adding 3.1 mL of concentrated hydrochloric acid to 1,000 mL (33 fl oz) of water. The same **CAUTION** applies: add the concentrated acid to the water, not the water to the acid.

(d) When sampling for organic volatiles, semivolatiles, or pesticides/PCBs, rinse with pesticide grade isopropanol followed by rinsing with distilled or deionized water. When using isopropanol to decontaminate a sampler, the sampler must be allowed to completely air dry prior to reassembly.

MATERIALS SUMMARY

PROJECT: GENERAL AAP

Date: Oct-Nov 1987

Brand/Description (Example Entries)	Material Source/Supplier (Example Entries*)	(Example Entries*)
PVC casing	4.0" ID, Schedule 40, flush threaded;	ABC Mfg; Aville, Minnesota 2" ID, Schedule 40, flush
threaded		
PVC screen	0.05" slot, 4.0" ID; Schedule 40,	ABC Mfg; Aville, Minnesota flush threaded, 0.02" slot, 2" ID; Schedule 40, flush threaded
Bentonite (drilling fluid and grout) Wyoming	Tru-gel	A. O. Bentonite; Bville,
Granular bentonite (seal)	Gran-Bent	White Mud, Cville, Montana
Bentonite pellets (seal)	(No brand name available)	PELBENT, Dville, Utah
Sand (filter pack)	8-12 silica sand	State Sand, Mville,
Colorado; supplier:		
EFG Co., Eville, Utah		
Cement (grout)	Portland Type II	A. Lumber Co., Eville, Utah
Drilling water	St. Peter Sandstone	Production Well #1, Tap at
well house		
Drilling rod lubricant	Slick Turn	Oil Products Co., Fville,
Texas		
Air compressor oil	Oil #40	Oil Products Co., Fville,

Figure 3-3. Example materials summary

(3) Additional acquisition, preservation, and handling criteria for the chemical analysis of soils are found in EM 200-1-3.

f. Liners. If sample liners are used, the following should apply:

(1) Use clear liners or take extra samples to ensure that the sample is of sufficient quantity and quality for the intended analyses;

(2) Liner seams and ends should be "airtight," i.e., "moisture impermeable";

(3) Borehole/drilling fluids should not be trapped within the liner;

(4) Liner or sealant interaction with the sample should not alter the sample's chemical composition; and

(5) Liners must be free of contamination and be decontaminated prior to use. Decontamination may not be necessary if the liners have been packaged by the manufacturer and has intact packaging up to the time of use.

g. Location. All soil samples, except those for physical and/or chemical analysis and reference should remain onsite, neatly stored at an FA-designated location. The disposition of these samples should be arranged by the FA. Samples from HTRW sites may have to be stored, and later disposed of, off site. Depending on the site and its accessibility to the public, it may be permissible (depending on state regulations) to stage the drums neatly on pallets immediately adjacent to the boring/monitoring well location. If the option exists to dispose of IDW by spreading it on the ground at the sampling location, it may not be cost-effective to stage the drums in a central location and then move them back to the boring/monitoring well location for disposal. Sample retention and disposal should be given detailed attention in the SAP.

3-12. Rock Coring

Bedrock should be cored unless the drilling plan specifies otherwise. Coring, using a diamond- or carbide-studded bit (ASTM D 2113), produces a generally intact sample of the bedrock lithology, structure, and physical condition. The use of a gear-bit, tricone, etc., to penetrate bedrock should only be considered for the confirmation of the "top of rock" (where penetration is limited to a few meters [feet]), the enlargement of a previously cored hole, or the drilling of highly fractured intervals. Except as noted below, guidance for preserving, storing, photographing, marking, cataloging, and handling of rock core samples may be found in ASTM D 5079.

a. The coring of bedrock or any firm stratigraphic unit should be conducted in a manner to obtain maximum intact recovery. The physical character of the bedrock (i.e., fractures, poor cementation, weathering, or solution cavities) may lessen recovery, even with the best of drillers and equipment.

b. The minimum core size should be an "N" series, 50 mm (2 [plus]-in.) diameter. Larger bit (hence, core) diameters may be needed to enhance core recovery.

c. While drilling in bedrock, and especially while coring, drilling fluid pressures should be adjusted to minimize drilling fluid losses and hydraulic fracturing. All pumping pressures should be recorded.

d. Rock cores should be stored in covered core boxes to preserve their relative position by depth. Intervals of lost core should be noted in the core sequence. Boxes should be marked on the cover (both inside and outside) and on the ends to provide project name, boring number, cored interval, and box number in cases of multiple boxes. Any core box known or suspected to contain contaminated core should be appropriately marked on the log and on the box cover (inside and out), and on both ends. The weight of each fully loaded box should not exceed 34 kg (75 lb). No geotechnical or contaminant data should appear on or within the box that is not specified on the boring log. As a minimum, the estimated number of boxes required for a given boring should be on hand prior to coring that site.

e. The core within each completed box should be photographed after the core surface has been cleaned or peeled, as appropriate, and wetted. Each photo should be in sharp focus and contain a legible scale in centimeters (feet and tenths of feet). The core should be oriented so that the top of the core is at the top of the photo. Each photo should be annotated on the back with the project name, bore/well designation, box number, cored depths pictured, and date photographed. One set of glossy color prints should be sent to the FA after the last coring. In addition, all negatives should be delivered to the FA after the FA has received the prints. (See ER 1110-1-1803 for additional guidance on core management.)

f. All rock core, except that for analysis and reference, should be neatly stored at an FA-designated location. The disposition of these samples should be arranged by the FDO. Specific instructions for the storage or required packaging and method of shipment to the laboratory should be provided in the drilling plan.

g. Bedrock cores known or suspected of being contaminated may have to be handled, stored, tested, and/or disposed of as hazardous waste. Such a consideration and determination should be made prior to drilling plan approval. This determination may alter drilling methods, coring frequency, data quality, costs, etc. Geophysical downhole logging or borehole camera techniques could be considered as alternatives in some cases. The drilling plan should reflect the final decision and possible alternatives that retain viability.

3-13. Abandonment/Decommissioning

Abandonment (also termed decommissioning) is that procedure by which any boring or well is permanently closed. Abandonment/decommissioning procedures should preclude any current or subsequent fluid media from entering or migrating within the subsurface environment along the axis or from the endpoints of any boring or well penetrating that environment.

a. Planned abandonment requirements and procedures should be described in the FSP plan and incorporate USACE guidance and applicable state and/or Federal regulatory abandonment requirements.

b. The closure of any borings or wells not scheduled for abandonment per drilling plan should be approved by the FA prior to any casing removal, sealing, or back-filling. Abandonment requests should be submitted by the FDO to the FA with the following data, plus recommendation:

(1) Designation of boring/well in question;

(2) Current status (depth, contents of hole, stratigraphy, water level, etc.);

(3) Reason for closure; and

(4) Action taken, to include any replacement boring or well.

c. Each boring or well to be abandoned/decommissioned should be sealed by grouting from the bottom of the boring/well to the ground surface. This should be done by placing a tremie pipe to the bottom of the boring/well (i.e., to the maximum depth drilled/bottom of well screen) and pumping grout through this pipe until undiluted grout flows from the boring/well at ground surface. Any open or ungrouted portion of the annular space(s) between the innermost well casing and borehole (to include any casings in between) should be grouted in the same manner.

d. After 24 hours, the FDO should check the abandoned site for grout settlement. That day, any settlement depression should be filled with grout and rechecked 24 hours later. Additional grout should be added using a tremie pipe inserted to the top of the firm grout, unless the depth of the unfilled portion of the hole is less than 4.5 m (15 ft) and this portion is dry. This process should be repeated until firm grout remains at ground surface.

e. An abandoned well may be grouted with the well screen and casing in place. However, local regulations or a lack of data concerning well construction, condition, or other factors may require the removal of the well materials and a partial or total hole redrilling prior to sealing the well site. See ASTM Standard Guide D 5299 for a discussion of other decommissioning procedures.

f. For each abandoned boring/well, a record should be prepared to include the following as applicable.

(1) Project and boring/well designation.

(2) Location with respect to the replacement boring or well (if any); e.g., 6 m (20 ft) north and 6 m (20 ft) west of Well 14.

(3) Open depth of well/annulus/boring prior to grouting.

(4) Casing or items left in hole by depth, description, composition, and size.

(5) Copy of the boring log.

(6) Copy of construction diagram for abandoned well.

(7) Reason for abandonment.

(8) Description and total quantity of grout used initially.

(9) Description and daily quantities of grout used to compensate for settlement.

(10) Dates of grouting.

(11) Disposition of materials removed/displaced from decommissioned boring/well; e.g., objects, soil, and groundwater.

(12) Water or mud level (specify) prior to grouting and date measured.

(13) Remaining casing above ground surface: type (well, drill, protective), height above ground, size, and composition of each.

(14) Report all depths/heights from ground surface.

(15) The original record should be submitted to the FA.

g. Replacement well/borings (if any) should be offset at least 6 m (20 ft) from any abandoned site in a presumed up- or cross-gradient groundwater direction.

3-14. Work Area Restoration and Disposal of Drilling and Cleaning Residue

All work areas around the wells and/or borings should be restored to a condition essentially equivalent to that of preinstallation. This includes the disposal of borehole cuttings and rut removal. Borehole cuttings, discarded samples, drilling fluids, equipment cleaning residue, and water removed from a well during installation, development, and aquifer testing should be disposed of in a manner approved by the FA, host installation, and consistent with applicable state and federal regulations. These types of materials are considered investigation-derived wastes (IDW). (See USEPA EPA/540/G-91/009 for USEPA guidance on the management of these materials.) Whatever procedures are followed, the leaving of barrels containing drill cuttings, excess samples, and water at various unsecured locations around the site at the completion of well installation is not appropriate. All drums/barrels filled onsite should be permanently labeled (in a waterproof manner and resistant to fading) and inventoried as to their contents and source. Restoration and disposal procedures (to include disposal location(s)) should be discussed in the FSP. Depending on the site and its accessibility to the public, it may be permissible (depending on state regulations) to stage the drums neatly on pallets immediately adjacent to the boring/monitoring well location. If the option exists to dispose of IDW by spreading it on the ground at the sampling location, it may not be cost-effective to stage the drums in a central location and then move them back to the boring/monitoring well location for disposal.

Chapter 4
Borehole Logging

4-1. General

Each boring log should fully describe the subsurface environment and the procedures used to gain that description. Guidance on field logging of subsurface explorations of soil and rock may be found in ASTM Standard Guide D 5434.

4-2. Format

All borings should be recorded in the field on Engineer (ENG) Form 1836 and 1836-A, per EM 1110-1-1804 (Figure 4-1) or on ENG Form 5056-R and 5056A-R, developed for HTRW work (see Figure 4-2). This guidance applies to in-house and contracted activities. Suggested data for recording are discussed throughout this manual. Because of the large quantity of information routinely required on logs at HTRW sites, a scale of 25 mm (1 in.) on the log equaling 300 mm (1 ft) of boring is usually adequate.

4-3. Submittal

Each original boring log should be submitted directly from the field to the FA after each boring is completed. In those cases where a monitoring well or other instrument is to be inserted into the boring, both the log for that boring and the installation diagram may be submitted together.

4-4. Original Logs and Diagrams

Only the "original" boring log (and diagram) should be submitted from the field to the FA. Carbon, typed, or reproduced copies are not considered "original." The original should be of sufficient legibility and contrast to provide comparable quality in reproduction.

4-5. Time of Recording

Logs should be recorded directly in the field without transcribing from a field book or other document. This technique lessens the chance for errors of manual copying and allows the completed document to be field-reviewed closer to the time of drilling.

4-6. Routine Entries

In addition to the data desired by the FDO and uniquely required by the drilling plan, the information should include those items listed in ASTM Standard Guide D 5434, except items under section 6.1.4 in D 5434. The other exceptions would be weather conditions, and certain items concerning sample handling procedures in sections 6.1.6 and 6.1.7 in D 5434. Sample handling procedures are required to be entered in the field logbook that is described in EM 200-1-3. The following information should also be routinely entered on the boring log.

a. Each boring and well (active and abandoned) should be uniquely numbered and located on a sketch map as part of the log.

b. Depths/heights should be recorded in meters (feet) and decimal fractions thereof (millimeters or tenths of feet). English units are acceptable if typically used by the site geologist.

c. Field estimates of soil classifications shall be in accordance with ASTM Standard Practice D 2488 and shall be prepared in the field at the time of sampling by the geologist. Guidance on soil and rock classification may also be found in EM 1110-1-1906, Spigolon 1993, Murphy 1985 and U.S. Army FM 5-410.

d. Each soil sample taken should be fully described on the log. The descriptions of intact samples should include the parameters shown in Table 4-1.

e. In the field, visual numeric estimates should be made of secondary soil constituents; e.g., "silty sand with 20 percent fines" or "sandy gravel with 40 percent sand." If such terms as "trace," "some," "several," etc., are used, their quantitative meaning should be defined on each log.

f. When used to supplement other sampling techniques, disturbed samples (e.g., wash samples, cuttings, and auger flight samples) should be described in terms of the appropriate soil/rock parameters to the extent practical. "Classification" should be minimally described for these samples along with a description of drill action and water losses/gains for the corresponding depth. Notations should be made on the log that these descriptions are based on observations of disturbed material rather than intact samples.

g. Rock core should be fully described on the boring log. Typical rock core parameters are shown in Table 4-2.

h. For rock core, a scaled graphic sketch of the core should be provided on or with the log, denoting by depth, location, orientation, and nature (natural or coring-induced) of all core breaks. Also mark the breaks purposely made to fit the core into the core boxes. If fractures are too numerous to be individually shown, their location may be drawn as a zone and described on the log. Also note, by

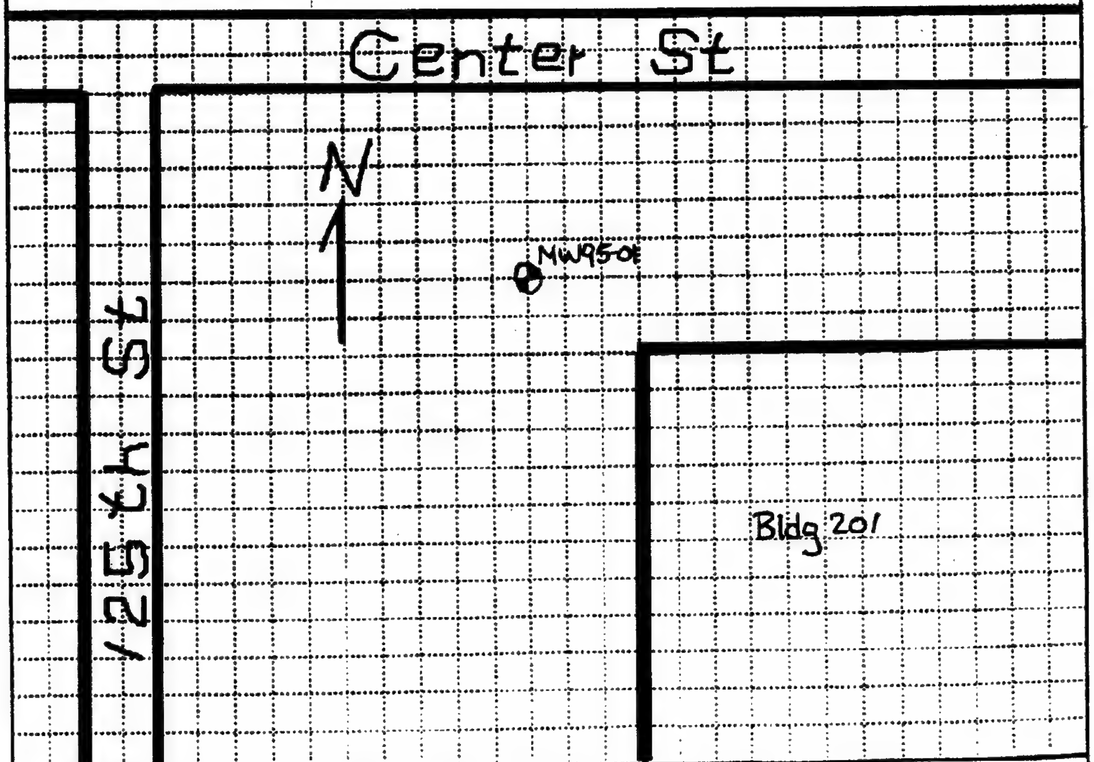
HTRW DRILLING LOG

HTRW DRILLING LOG	DISTRICT: OMAHA	HOLE NUMBER: MW95-01
1. COMPANY NAME: CONTRACTING FIRM, INC.	2. DRILL SUBCONTRACTOR: SUBCONTRACT DRILLERS, INC	SHEET 1 OF 3 SHEETS
3. PROJECT: BIG SUPERFUND SITE	4. LOCATION: Site A	
5. NAME OF DRILLER: JOE SUPER DRILLER	6. MANUFACTURER'S DESIGNATION OF DRILL: CME-75 Milwaukee Heavy Duty Drill Rig	
7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT: CME-75, using 4 1/4" hollow stem augers, 3" O.D. stainless steel split-spoons (chemical and geotech), bullet bit (outer) drag bit (inner)	8. HOLE LOCATION: See Map Below	
	9. SURFACE ELEVATION: Not Yet Available	
	10. DATE STARTED: 8-6-95	11. DATE COMPLETED: 8-7-95
12. OVERBURDEN THICKNESS: 12.0'	15. DEPTH GROUNDWATER ENCOUNTERED: 5.0'	
13. DEPTH DRILLED INTO ROCK: ϕ	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED: 4.5' TOC ~72 hours (in well)	
14. TOTAL DEPTH OF HOLE: 12.0'	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY)	

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES		
	ϕ	ϕ	ϕ		
20. SAMPLES FOR CHEMICAL ANALYSIS	**VOC**	**METALS**	**OTHER (SPECIFY)**	**OTHER (SPECIFY)**	**OTHER (SPECIFY)**
			BTEX 4x4oz	TRPH 2x8oz	Lead 2x8oz
22. DISPOSITION OF HOLE	**BACKFILLED**	**MONITORING WELL**	**OTHER (SPECIFY)**	**23. SIGNATURE OF INSPECTOR**	
		8-6-92		Field Geologist	

21. TOTAL CORE RECOVERY: ϕ %

LOCATION SKETCH/COMMENTS — SCALE: 1" = 20'



PROJECT: BIG SUPERFUND SITE — HOLE NO. MW95-01

ENG FORM 5056-R, AUG 94 (Proponent: CECW-EG)

Figure 4-1. Boring log format (Sheet 1 of 3)

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE NUMBER: MW95-01

PROJECT: BIG SUPERFUND SITE | INSPECTOR: Field Geologist | SHEET 2 OF 3 SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
	0 – 2	SC - Clayey Sand, medium dense, nonplastic, noncemented, dry, medium brown, fine grained, sub-rounded, 15-20% pieces of concrete	Calibrated Hnu w/ isobutylene at 55 ppm at 190 psi BACKGROUND = 0.8 BREATH = 0.8 SCREEN = 0.9	0.0 1.3' NO SAMPLE OR RECOVERY	S-MW01-02/BT 2x4oz jar -02/T 1x8oz jar -02/L 1-8oz jar	5 10 12 12	Drilling in cow pasture - numerous manure piles - may be increasing Hnu readings N (Blow) = 22 Rec (Recovery) = 1.3' TIME - 1012
	3 – 5	SC - Clayey sand, same as above	BREATH = 0.8 SCREEN = 0.7	3.0' 4.8'		9 9 12 11	N = 21 Rec = 1.8' Time - 1019
	5 – 8						Plug came off end of central rod. Tried driving split spoon - no recovery. Offset ~1.5' and drilled back down to 8.0'
	8 – 10	CL - Sandy Lean Clay, stiff, low to medium plastic, noncemented, moist, ~15% very fine-grained sand, dark brown SP - Poorly Graded Sand, loose, non-plastic, noncemented, dry to slightly moist, light brown to white, very fine to fine-grained		8.0' 10.0'		2 4 5 6	N = 9 Rec = 2.0' TIME = 1048

PROJECT: BIG SUPERFUND SITE | HOLE NO. MW95-01

ENG FORM 5056A-R, AUG 94 (Proponent: CECW-EG)

Figure 4-1. (Continued) (Sheet 2 of 3)

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE NUMBER: MW95-01

PROJECT: BIG SUPERFUND SITE | INSPECTOR: Field Geologist | SHEET 3 OF 3 SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
	10	SP- Poorly Graded Sand, dense, non-plastic, patchy light cementation, moist, light brown to grayish white, very fine to fine-grained, subrounded	Breath = 0.8 Screen = 0.7	10.0		6	N=80
	11					24	Rec = 2.0'
						56	Time - 1144
				12.0'		60	
	12	BOTTOM OF HOLE = 12.0'					Bailed sand from inside bottom of augers. Installed well to top of seal. 8-7-95 - Grouted to surface. Did surface completion. See attached well construction diagram.
	13						
	14						
	15						
	16						
	17						
	18						
	19						
	20						

PROJECT: BIG SUPERFUND SITE | HOLE NO. MW95-01

ENG FORM 5056A-R, AUG 94 (Proponent: CECW-EG)

Figure 4-1. (Concluded) (Sheet 3 of 3)

HTRW DRILLING LOG	DISTRICT	HOLE NUMBER
1. COMPANY NAME	2. DRILLING SUBCONTRACTOR	SHEET OF SHEETS

3. PROJECT	4. LOCATION
5. NAME OF DRILLER	6. MANUFACTURER'S DESIGNATION OF DRILL
7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT	8. HOLE LOCATION
	9. SURFACE ELEVATION
	10. DATE STARTED / 11. DATE COMPLETED
12. OVERBURDEN THICKNESS	15. DEPTH GROUNDWATER ENCOUNTERED
13. DEPTH DRILLED INTO ROCK	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED
14. TOTAL DEPTH OF HOLE	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY)

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR

LOCATION SKETCH/COMMENTS SCALE:

PROJECT	HOLE NO.

Figure 4-2. HTRW Drilling Log

HTRW DRILLING LOG (CONTINUATION SHEET)		HOLE NUMBER
PROJECT	INSPECTOR	SHEET OF SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)

PROJECT	HOLE NO.

ENG FORM 5056A-R, AUG 94 (Proponent: CECW-EG)

Figure 4-2 (Concluded)

Table 4-1
SOIL PARAMETERS FOR LOGGING

PARAMETER	EXAMPLE
Classification	Sandy clay
Depositional environment and formation, if known	Glacial till, Twin Cities Formation
ASTM D 2488 Group Symbol	CL (field estimate)
Secondary components and estimated percentages	Sand: 25 percent Fine sand 5 percent Coarse sand 20 percent
Color (Soil color charts such as Munsell Soil or the Geological Society of America (GSA) Rock Color Chart are helpful for describing the color of soil samples. If a color chart is used, give both narrative and numerical description and note which chart was used. Suggested standard colors can be found in Spigolon 1993)	Gray: (Gr) (7.5 YR 5.0 (Munsell))
Plasticity	Low plasticity
Consistency (cohesive soil)	Very soft, soft, medium stiff, very stiff, hard
Density (noncohesive soil)	Loose, medium loose, dense, very dense
Moisture content Use a relative term. Avoid a percentage unless a value has been measured.	Dry, moist, wet, saturated
Structure and orientation	No apparent bedding: numerous vertical, iron-stained, tight fractures
Grain angularity	Rounded

depth, the intervals of all lost core and hydrologically significant details. This sketch should be prepared at the time of core logging, concurrent with drilling.

i. A record of the brand name and amount of any bentonite used for each boring should be made on the log, along with the reason for and start (by depth) of this use. If measured, record mud viscosities and weight.

j. The drilling equipment used should be generally described on each log. Include such information as rod size, bit type, pump type, rig manufacturer, and model.

k. Each log should record the drilling sequence; e.g.:

(1) Opened hole with 8-in. auger to 9 ft;

(2) Set 8-in. casing to 10 ft;

(3) Cleaned out and advanced hole with 8-in. roller bit to 15 ft (clean water, no water loss);

(4) Drove 1-3/8-in. ID X 2-in. outside diameter (OD) sampler to 16.5 ft;

(5) Advanced with 8-in. roller bit to 30 ft, 15-gal water loss;

(6) Drove 1-3/8-in. ID X 2-in. OD sampler to 31.5 ft;

(7) Hole heaved to 20 ft; and

(8) Mixed 25 lb of ABC bentonite in 100 gal of water for hole stabilization and advanced with 8-in. roller bit to 45 ft, etc.

l. All special problems and their resolution should be recorded on the log; e.g., hole squeezing, recurring problems at a particular depth, sudden tool drops, excessive grout takes, drilling fluid losses, unrecovered tools in hole, lost casings, etc.

m. The dates and times for the start and completion of borings should be recorded on the log along with notation by depth for drill crew shifts and individual days.

n. Each sequential boundary between the various soils and individual lithologies should be noted on the log by depth. When depths are estimated, the estimated range

Table 4-2
ROCK CORE PARAMETERS FOR LOGGING

PARAMETER	EXAMPLE
Rock type	Limestone, sandstone, granite
Formation	Anytown Formation
Modifier denoting variety	Shaly, calcareous, siliceous, micaceous
Bedding/banding characteristics	Laminated, thin bedded, massive, cross bedded, foliated
Color (Color charts such as Munsell or the GSA Rock Color Chart are helpful for describing the color of rock samples. If a color chart is used give both narrative and numerical description and note which chart was used. Suggested standard colors can be found in Spigolon 1993).	Light brown: (lBr)
Hardness	Soft, very hard
Degree of cementation	Poorly cemented, well cemented
Texture	Dense, fine-, medium-, coarse-grained, glassy, porphyritic, crystalline
Structure and orientation	Horizontal bedding, dipping beds at 30 degrees, highly fractured, open vertical joints, healed fractures, slickensides at 45 degrees, fissile
Degree of weathering	Unweathered, slightly weathered, highly weathered
Solution or void conditions	Solid, cavernous, vuggy with partial infilling by clay
Primary and secondary permeability, include estimates and rationale	Low primary; well cemented High secondary: several open joints
Lost core interval and reason for loss	50-51 ft, noncemented sandstone likely

should be noted along the boundary.

o. The depth of first encountered free water should be indicated along with the method of determination; e.g., "37.6 ft from direct measurement after drilling to 40.0 ft"; "40.1 ft from direct measurement in 60-ft hole when boring left overnight, hole dry at end of previous shift"; or "25.0 ft based on saturated soil sample while sampling 24-26 ft." Any other distinct water level(s) found below the first should also be described.

p. The interval by depth for each sample taken, classified, and/or retained should be noted on the log. Record the length of sampled interval, length of sample recovery, and the sampler type and size (diameter and length).

q. A record of the blow counts, hammer type and weight, and length of hammer fall for driven samplers should be made. For thin wall samplers, indicate whether the sampler was pushed or driven and the pressure/blow count per drive. Blow counts should be recorded in 150 mm (0.5 ft) foot increments when standard penetration (ASTM D 1586) samplers (35 mm [1-3/8 in.] ID X 50 mm [2 in.] OD) are used. For penetration less than a half foot, annotate the count with the distance over which the count was taken. Blow counts, in addition to their engineering significance, may be useful for stratigraphic correlation. (See Hsai-Wong Fang (1991) for interpretation of blow counts when 75-mm (3-in.) samplers are used).

r. When drilling fluid is used, a quantitative record should be maintained of fluid losses and/or gains and the interval over which they occur. Adjustment should be made for fluid losses due to spillage and intentional wasting (e.g., recirculation tank cleaning) to more closely estimate the amount of fluid lost to the subsurface environment.

s. Record the drilling fluid pressures typically used during all drilling operations (aqueous and pneumatic) and the driller's comments on drillability, drill speed, down pressure, rotation speed, etc.

t. Note the total depth of drilling and sampling on the log.

u. Record significant color changes in the drilling fluid return, even when intact soil samples or rock core are being obtained. Include the color change (from and to), depth at which change occurred, and a lithologic description of the cuttings before and after the change.

v. Soil gas readings, if taken, should be recorded on the log. Each notation should include interval sampled and reading. A general note on the log should indicate meter manufacturer, model, serial number, and calibration material. If several meters are used, key the individual readings to the specific meter.

w. Special abbreviations used on a log and/or well diagram should be defined in the log/diagram where used.

Chapter 5
Monitoring Well Installation

5-1. General

A monitoring well is a device designed for the acquisition of groundwater samples that represent the chemical quality of the aquifer adjacent to the screened interval, unbiased by the well materials and installation process, and which provides access to measure the potentiometric surface for that screened interval. The screened interval consists of that portion of the device that is directly open (e.g., horizontally adjacent) to the host aquifer by way of openings in the well casing (hereafter called the "screen") AND indirectly open (e.g., vertically adjacent) to the aquifer by way of the filter pack (or other permeable material) extending below and/or above the screen. While the maximum length of the screened interval is fixed for a given well (by the length of the filter pack), the effective or functional length may vary with water table fluctuations or sampling techniques. Additional guidance on monitoring well installation may be found in ASTM D 5092.

5-2. Well Clusters

Each monitoring well is a mechanism through which to obtain a representative sample of groundwater and, to measure the potentiometric surface in that well. To help ensure this representation in the case of well clusters, each well of a cluster should be installed in a separate boring. Multiple well placements in a single boring are too difficult for effective execution and evaluation to warrant single hole usage.

5-3. Well Screen Usage

Each overburden well should have a screen, as per Figure 5-1, 5-2, or 5-3 (or of a technically equivalent construction as in ASTM D 5092). Under normal conditions, the extra effort for screen installation in bedrock wells can be more than offset by the assurance of an unobstructed opening to the required depth during repeated usage. When conditions permit, and when allowed by state or local law, an open, unscreened well may be constructed in firm stable bedrock. However, well integrity and consistent access to the original sampled interval during prolonged monitoring must be maintained.

5-4. Beginning Well Installation

a. The installation of each monitoring well should begin within 12 hours of boring completion for holes uncased or partially cased with temporary drill casing. Installation should begin within 48 hours in holes fully cased with temporary drill casing. Once installation has begun, no breaks in the installation process should be made until the well has been grouted and drill casing removed. Anticipated exceptions should be requested in writing by the FDO to the FA prior to drilling. Data to include in this request are:

(1) Well(s) in question;

(2) Circumstances; and

(3) Recommendations and alternatives.

b. In cases of unscheduled delay such as personal injury, equipment breakdowns, or sudden inclement weather or scheduled delays such as borehole geophysics, no advance approval of delayed well installation should be needed. In those cases, resume installation as soon as practicable. However, partially completed borings should be properly secured during periods of drilling inactivity to preclude the entry of foreign materials or unauthorized personnel to the boring. In cases where a partially cased hole into bedrock is to be partially developed prior to well insertion, the well installation should begin within 12 hours after this initial development.

c. Temporary casing and hollow stem augers may be withdrawn from the boring prior to well installation if the potential for cross-contamination is not likely and if the borehole walls will not slough during the time required for well installation. This procedure is usually successful in firm clays and in bedrock that is not intensely fractured or highly weathered.

d. If the borehole will not remain stable long enough to complete placement of all necessary well materials in their proper position, it may be necessary to install some or all of the well materials prior to removal of the casing or hollow stem augers. In this situation, the hollow stem augers or casing should have an inside diameter sufficient to allow the installation of the prescribed diameter screen and casing plus annular space for a pipe through which to place the filter pack and grout.

e. Any materials, especially soils, blocking the bottom of the drill casing or hollow stem auger should be dislodged and removed from the casing prior to well insertion. This action both reduces the potential for cross--contamination and makes well installation easier.

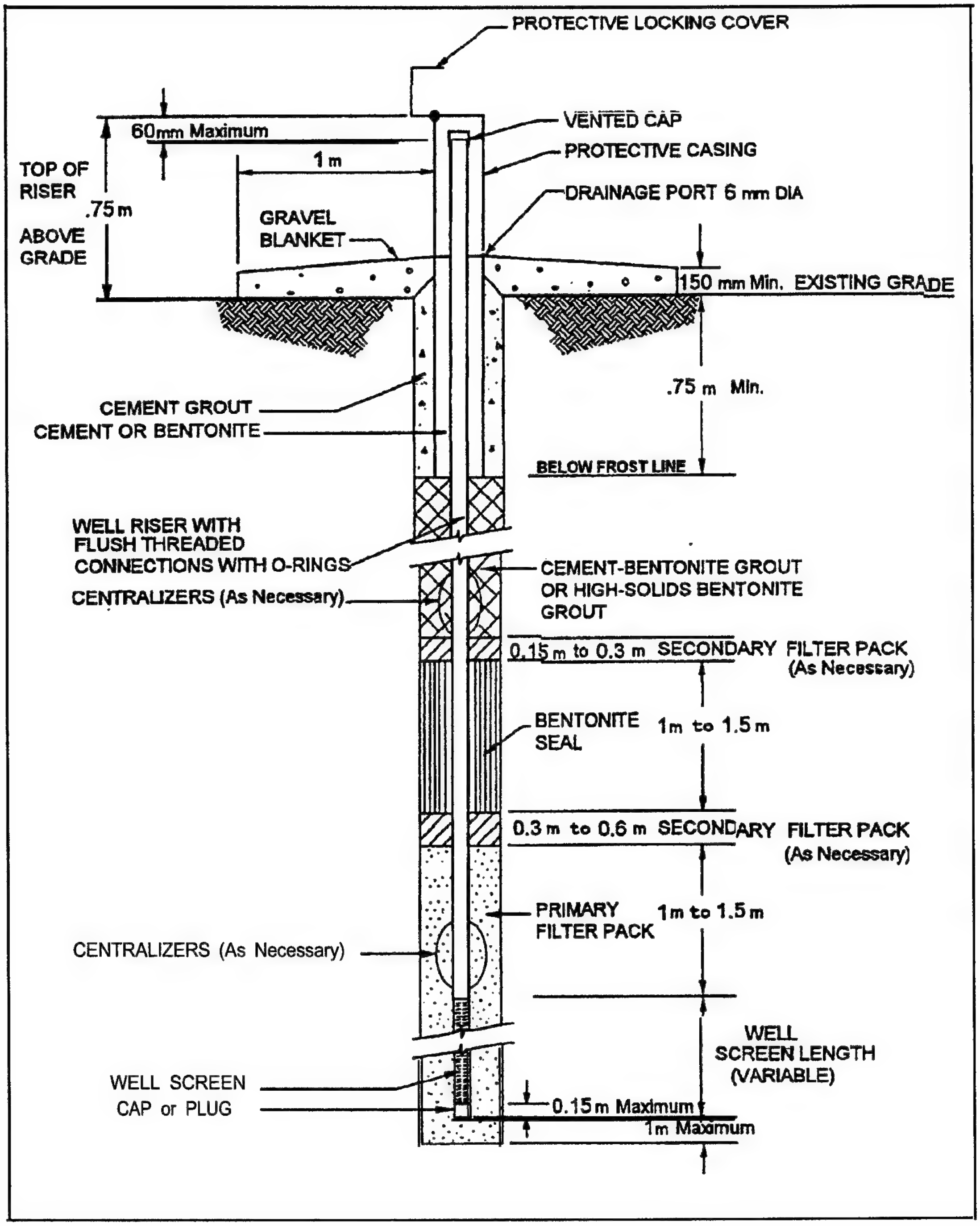


Figure 5-1. Schematic construction of single-cased well with gravel blanket

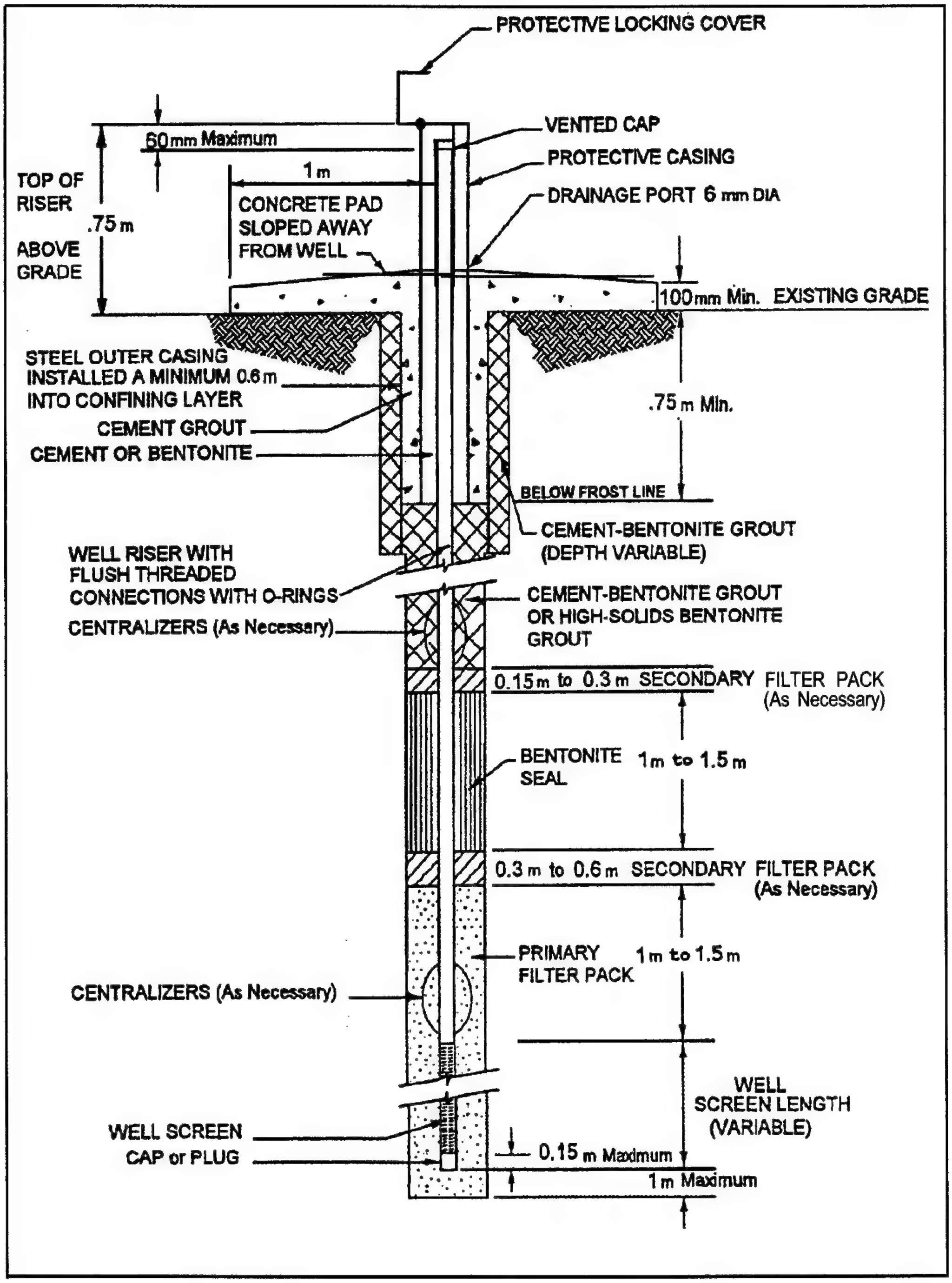


Figure 5-2. Schematic construction of multi-cased well with concrete pad

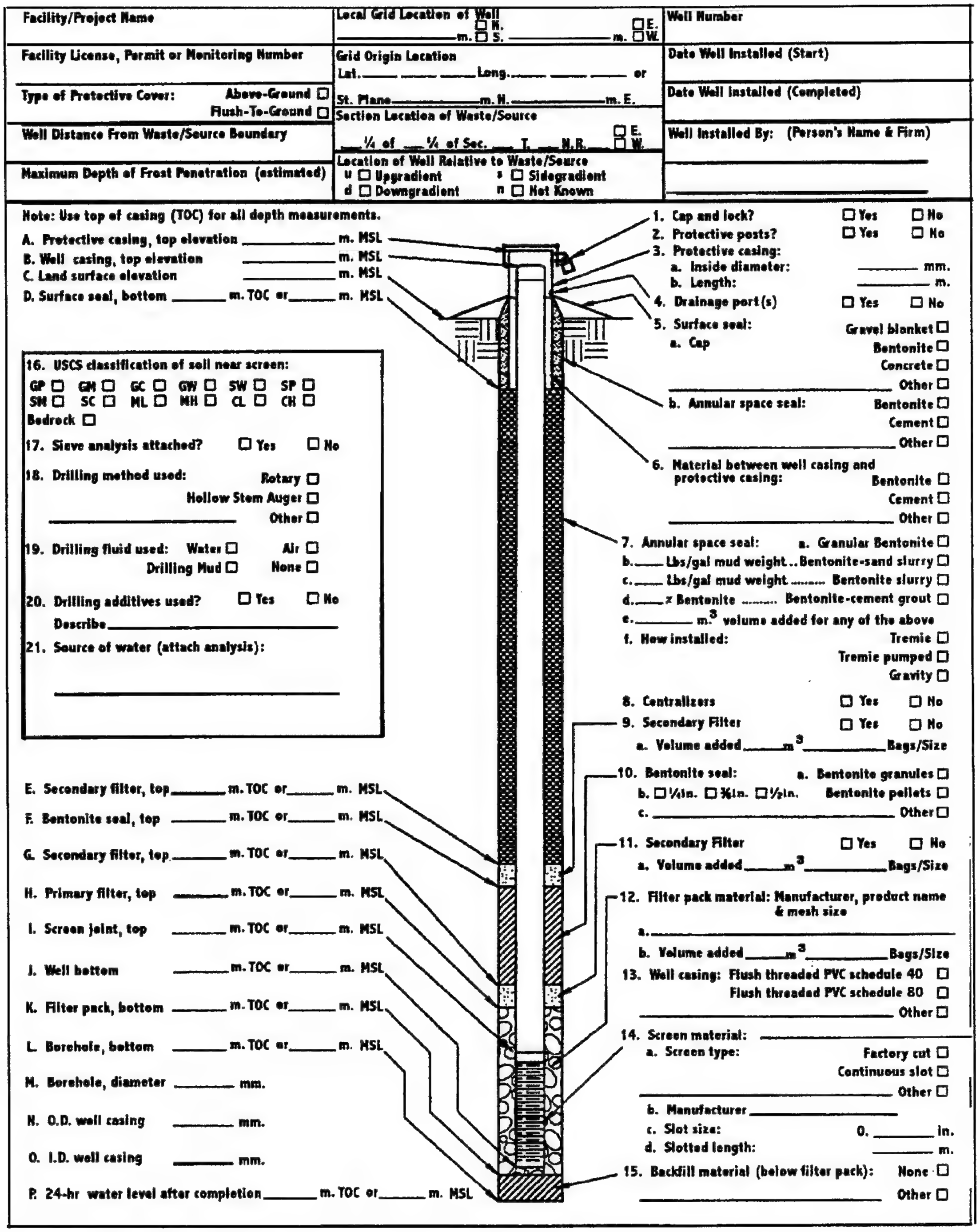


Figure 5-3. Schematic construction diagram of monitoring well

f. Once begun, well installation should not be interrupted due to the end of the driller's work shift, darkness, weekend, or holiday.

g. If possible, the FDO should ensure that all materials and equipment for drilling and installing a given well are available and onsite prior to drilling that well. The FDO should have all equipment and materials onsite prior to drilling and installing any well if the total well drilling and installation effort is scheduled to take 14 days or less. For longer schedules, the FDO should ensure that the above-mentioned materials needed for at least 14 days of operation are onsite prior to well drilling. The balance of materials should be in transit prior to well drilling. Any site-specific factors that preclude the availability of needed secure storage areas should be identified and resolved in the drilling plan.

5-5. Screens, Casings, and Fittings

a. All well screens and well casings should be free of foreign matter (e.g., adhesive tape, labels, soil, grease, etc.) and washed with approved water prior to use. Prewashing may not be necessary if the materials have been packaged by the manufacturer and have their packaging intact up to the time of installation. Pipe nomenclature stamped or stenciled directly on the well screen and/or blank casing within and below the bentonite seal should be removed by means of SANDING, unless removable in approved water. Solvents, except approved water, should NOT be used for removal of marking. Washed screens and casings should be stored in plastic sheeting until immediately prior to insertion into the borehole.

b. Bottoms of well screens should be placed no more than 1 m (3 ft) above the bottom of the drilled borehole. If significant overdrilling is required (as for determining stratigraphy), a pilot boring should be used. The intent here is to narrow the interval of aquifer being sampled, limit the potential for stagnant or no-flow areas near the screen, and preclude unwanted backfill materials (e.g., grout or bentonite) from entering or passing through the interval to be screened and sampled. The casing/screen should be suspended from the surface and should not rest on the bottom of the borehole during installation of the filter pack and annular seal.

c. All screen bottoms should be securely fitted with a threaded cap or plug of the same composition as the screen. This cap/plug should be within 150 mm (0.5 ft) of the open portion of the screen. No solvents or glues should be permitted for attachment.

d. Silt or sediment traps (also called cellars, tail pipes, or sumps) should NOT be used. A silt trap is a blank length of casing attached to and below the screen. Trap usage fosters a stagnant, turbid environment which could influence analytical results for trace concentrations.

e. The top of each well should be level such that the difference in elevation between the highest and lowest points on the top of the well casing or riser should be less than or equal to 6 mm (0.02 ft).

f. The borehole should be of sufficient diameter to permit at least 50 mm (2 in.) of annular space between the borehole wall and all sides of the well (centered riser and screen). When telescoping casings (one casing within another), the full 50 mm (2-in.) annulus may not be practical or functional. In this case, a smaller spacing may be acceptable, depending on site specifics.

g. Well screen lengths may be a function of hydrostratigraphy, temporal considerations, environmental setting, analytes of concern, and/or regulatory mandate. Screen lengths should be specified in the drilling plan.

h. The actual inside diameter of a nominally sized well is a function of screen construction and the wall thickness/schedule of both the screen and casing. In the case of continuously wound screens, their interior supporting rods may reduce the full inside diameter. This consideration is critical when planning the sizes for pumps, bailers, surge devices, etc.

i. When physical or biological screen clogging is anticipated, the larger open-area per unit length of continuously wound screens has an advantage over the slotted variety.

5-6. Granular Filter Pack

a. When artificial filter packs are used, a tremie pipe for filter pack placement is recommended, especially when the boring contains drilling fluid or mud. A record should be maintained of the amount of water used to place the filter pack, which should be added to the volume of water to be removed during well development.

b. The filter pack should extend from the bottom of the boring to 1 to 1.5 m (3 to 5 ft) above the top of the screen unless otherwise specified in the drilling plan. This extra filter allows for settlement (from infiltration and compaction) of the filter pack during development and repeated sampling events. The additional filter helps to

maintain a separation between the bentonite seal and well screen.

c. Sometimes, depending on the gradation of the primary filter pack and the potential for grout intrusion into the primary filter pack, a secondary filter pack may be installed above the primary filter pack to prevent the intrusion of the bentonite grout seal into the primary filter pack. To be effective, the secondary filter should extend 0.3 to 0.6 m (1 to 2 ft) above the primary filter pack.

d. The final depth to the top of the granular filter should be directly measured (by tape or rod) and recorded. Final depths should not be estimated, for example, as based on volumetric measurements of placed filter.

5-7. Bentonite Seals

a. Bentonite seals, especially those set in water, should typically be composed of commercially available pellets. Pellet seals should be 1 to 1.5 m (3 to 5 ft) thick as measured immediately after placement without allowance for swelling. Granular bentonite may be an alternate if the seal is set in a dry condition. Tremie pipes are not recommended.

6. Slurry seals can be used when the seal location is too far below water to allow for pellet or containerized-bentonite placement or within a narrow well-borehole annulus. Typically, the specific gravity of cement grout placed atop the slurry seal will be greater than that of the slurry. Therefore, the intent to use a slurry seal should be detailed in the drilling plan, and details should include a discussion of how the grout will be precluded from migrating through the slurry. Slurry seals should have a thick, batter-like (high viscosity) consistency with a placement thickness of 1 to 1.5 m (3 to 5 ft). Typically, only high-solids bentonite grouts are used that consist of a blend of powdered bentonite and fresh water mixed to a minimum 20 percent solids by weight of pumpable slurry with a density of 9.4 pounds per gallon or greater.

c. In wells designed to monitor possible contamination in firm bedrock, the bottom of the bentonite seal should be located at least 1 m (3 ft) below the top of firm bedrock, as determined by drilling. "Firm bedrock" refers to that portion of solid or relatively solid, moderately to unweathered bedrock where the frequency of loose and fractured rock is markedly less than in the overlying, highly weathered bedrock. Special designs will be needed to monitor contamination in fractured bedrock. Guidance on design of ground-water monitoring systems in karst and fractured-rock aquifers may be found in ASTM D 5717.

d. The final depth to the top of the bentonite seal should be directly measured (by tape or rod) and recorded. Final depths should not be estimated, as, for example, based on volumetric measurements of placed bentonite.

e. Numerous opinions have been expressed regarding bentonite hydration time, bentonite placement procedures under water versus in a dry condition, and the potential installation delays and other consequences caused by these factors. By not allowing sufficient time for the bentonite seal to hydrate and form a low permeable seal, grout material could infiltrate into the bentonite seal and possibly into the filter pack. It is recommended waiting a minimum of 3 to 4 hours for hydration of bentonite pellets, or tablets when cement grout is used above the bentonite seal. If bentonite chips are used, the minimum hydration time could be twice as long. Normally chips should only be used if it is necessary to install a seal in a deep water column. Because of their high moisture content and slow swelling tendencies, chips can be dropped through a water column more readily than a material with a low moisture content, such as pellets or tablets. Bentonite chips should not be placed in the vadose zone. A 1 m (3 ft) minimum bentonite pellet seal must be constructed to protect the screen and filter pack from downhole grout migration. When installing a bentonite seal in the vadose zone (the zone above the water table), water should be added to the bentonite for it to properly hydrate. The amount of water required is dependent on the formation. It is recommended that the bentonite seal be placed in 0.15 to 0.3 m (6 in to 1 ft) lifts, with each lift hydrated for a period of 30 minutes. This method will assure that the bentonite seal is well hydrated and accomplish its intended purpose. A 0.15 to 0.3 m (6 in. to 1 ft) layer of fine to medium sand (secondary filter pack) placed atop the bentonite seal may further enhance barrier resistance to downward grout migration.

5-8. Grouting

All prescribed portions of grout material should be combined in an aboveground rigid container and mechanically (not manually) blended to produce a thick, lump-free mixture throughout the mixing vessel. The mixed grout should be placed around the monitoring well as follows.

a. The grout should be placed from within a rigid side discharge grout pipe located just over the top of the seal. The grout or tremie pipe should be decontaminated prior to use.

b. Prior to exposing any portion of the borehole above the seal by removal of any drill casing (to include hollow-stem augers), the annulus between the drill casing and well

casing should be filled with sufficient grout to allow for planned drill casing removal. The grout should not penetrate the well screen or granular filter pack. Disturbance of the bentonite seal should be minimal.

(1) If all drill casing is to be removed in one operation, the grout should be pumped through the grout pipe until undiluted grout flows from the annulus at ground surface, forming a continuous grout column from the seal to ground surface. The drill casing should then be removed, making certain that borehole exposure to the atmosphere is minimal. During the removal of hollow stem augers, the grout pipe may have to be periodically reinserted for additional grouting to compensate for the larger annular space created by the augers' helical coil.

(2) If drill casing is to be incrementally removed with intermittent grout addition, the grout should be pumped through the grout pipe until it reaches a level that will permit at least 3 m (10 ft) of grout to remain in the well/drill casing annulus AFTER removing the selected length of drill casing. Using this method, at least 6 m (20 ft) of grout should be within the drill casing before removing 3 m (10 ft) of driven casing or considerably more than 6 m (20 ft) of grout for the removal of 3 m (10 ft) of hollow stem auger. With this method, the grout pipe needs only to be reinserted to the base of the casing yet to be removed before repeating the grout insertion process.

c. If the ungrouted portion of the hole is less than 4.5 m (15 ft) deep and without fluids after casing removal, the ungrouted portion may be filled by pouring grout from the surface without a pipe.

d. If drill casing (to include hollow-stem auger) was not used, grouting should proceed to surface in one continuous operation. Care should be taken, however, in deep wells when using cement grout around PVC casing. Extreme heat, commonly known as heat of hydration, can be generated by the cement during hydration and curing. The heat generated can be sufficient enough to soften or weaken PVC casing, resulting in collapse of the casing. Grouting in multiple lifts may be necessary in this situation.

e. Once begun, the grouting process should be continuous until all the drill casing has been removed and all annular spaces are grouted to the ground surface.

f. Protective casing should be installed on the same day as grouting begins.

g. The FDO should check the site for grout settlement and add more grout to fill any depression that day. Repeat this process until firm grout remains at ground surface. This process should be completed within 24 hours of the initial grout placement. Incremental quantities of grout added in this manner should be recorded on the well completion diagram to be submitted to the FA.

h. For grout placement in a dry and open hole less than 4.5 m (15 ft) deep, the grout may be manually mixed and poured in from the surface as long as seal integrity is maintained.

i. No grout should be placed or allowed to migrate below the bentonite seal and into the well screen.

5-9. Well Protection

a. Protective casing should be installed around each monitoring well the same day as initial grout placement. The annulus formed between the outside of the protective casing and borehole should be filled to the ground surface with grout. The annulus between the monitoring well and protective casing should be filled to a minimum of 150 mm (0.5 ft) above the ground surface with cement or bentonite as part of the overall grouting procedure. Specific details of well protection should be approved by the FA. These details and specific elements to be included in the well construction diagrams should be described in the drilling and well installation plan.

b. All protective casing should be steam or hot-water-pressure cleaned prior to placement; free of extraneous openings; and devoid of any asphaltic, bituminous, encrusting, and/or coating materials, except the black paint or primer applied by the manufacturer.

c. Recommended minimum elements of protection design include the following list.

(1) A 1.5 m (5-ft) minimum length new, black iron/steel pipe (protective casing) extending about 0.75 m (2.5 ft) above ground surface and set in grout (see Figures 5-1, 5-2, and 5-4). The bottom of the protective casing should extend below the frost line to preclude damage from frost heave.

(2) A protective casing inside diameter at least 100 mm (4 in.) greater than the nominal diameter of the well riser.

(3) A hinged cover or loose-fitting telescopic slip-joint cap to keep direct precipitation and cap runoff out of

the casing. Threaded covers should be avoided because of the tendency to rust or freeze shut.

(4) All protective casing covers/caps secured to the casing by means of a noncorrosive padlock from the date of protective casing installation. All manhole covers should also be lockable.

(5) If practical, have all padlocks at a given site opened by the same key. The FDO should provide four of these keys to an FA-designated representative at the project.

(6) No more than 60 mm (0.2 ft) from the top of the protective casing to the top of the well casing. This, or a smaller spacing, is needed for subsequent water-level determinations by some acoustical equipment which must rest upon the well casing in order to function.

(7) All painting of the protective casing must be done offsite, prior to installation. Only the outside of the casing should be painted. Each well should be identified by a number placed on the outside of the well casing. Various methods of identification have been successfully used such as painting the number on the protective casing with the help of a painting stencil, attaching a metal imprinted noncorrosive metal tag, or imprinting the number directly on the steel protective casing. The color of the casing, the well number and method of application should be specified by the design FA in the drilling and well installation plan, and should be in accordance with the requirements prescribed by the owner and state and local technical regulations. Painting should be completed and dry prior to initially sampling the well.

(8) The erection of protective posts should be considered when physical damage resulting from construction equipment or vehicles is likely. When necessary, steel posts should be erected with a minimum diameter of 80 mm (3 in.). Each post should be radially located a minimum of 1 m (3 ft) from the well and placed 0.6 to 1 m (2 to 3 ft) below ground surface, having 1 m (3 ft) minimally above ground surface. Posts are typically filled with concrete and set in post holes which are backfilled with concrete. The post should be painted orange using a brush. Installation should be completed prior to sampling the well. Flags or barrier markers in areas of high vegetation may be helpful.

(9) When posts are used in conjunction with concrete pads, the posts should be located **OUTSIDE** of the pad. Posts inside of a pad (especially near a comer or edge) may cause the pad to crack, either by normal stress relief or if severely struck as by a vehicle.

(10) The above-mentioned posts should be supplemented with three-strand barbed wire in livestock grazing areas. Post and wire installation should be installed prior to sampling.

(11) Place a 6 mm (1/4 in.) diameter hole (drainage port) in the protective casing centered, no more than 3 mm (1/8 in.) above the grout filled annulus between the monitoring well riser and the protective casing.

(12) The application of at least a 150 mm (0.5 ft) thick coarse gravel 19- to 75-mm (3/4- to 3-in.) particle size pad extending 1 m (3 ft) radially from the protective casing (see Figure 5-4 for layout and dimensions). Prior to placement of this gravel pad, any depression around the well should be backfilled to slightly above the level of the surrounding ground surface with uncontaminated cohesive soil. This will prevent a "bathtub" effect of water collecting in the gravel pad around the well casing. Construction of the gravel pad is suggested prior to development. Some long-term, heavy traffic, or high visibility locations may warrant a concrete pad specially designed for site conditions. Any concrete pad usage, especially in cold climates, should be designed to withstand frost heaving. Frost uplift may adversely affect well and pad integrity. A concrete pad should be at least 100 mm (4 in.) thick and 1 m (3 ft.) square. Round concrete pads are also acceptable.

(13) All elements of well protection should be detailed in the drilling plan. In addition, unique well protection requirements for floodplains, frost heaving, heavy traffic areas, parking lots, as well as wells finished at or below grade, and other special circumstances should also be covered on a case-by-case basis, in the drilling plan. As an example, a suggested well design to minimize the effects of frost heaving is shown in Figure 5-6. An example of a flush-to-ground completion is shown in Figure 5-5. Additional guidance on monitoring well protection may be found in ASTM Standard Practice D 5787.

5-10. Shallow Wells

Shallow, less than 4.5 m (15 ft), well construction may be more problematic than deep. Sufficient depth may not be available to utilize the full lengths of typical well components when the aquifer to be monitored is near the surface. The FA should tailor design criteria to the actual environment and project objectives for appropriate shallow well construction.

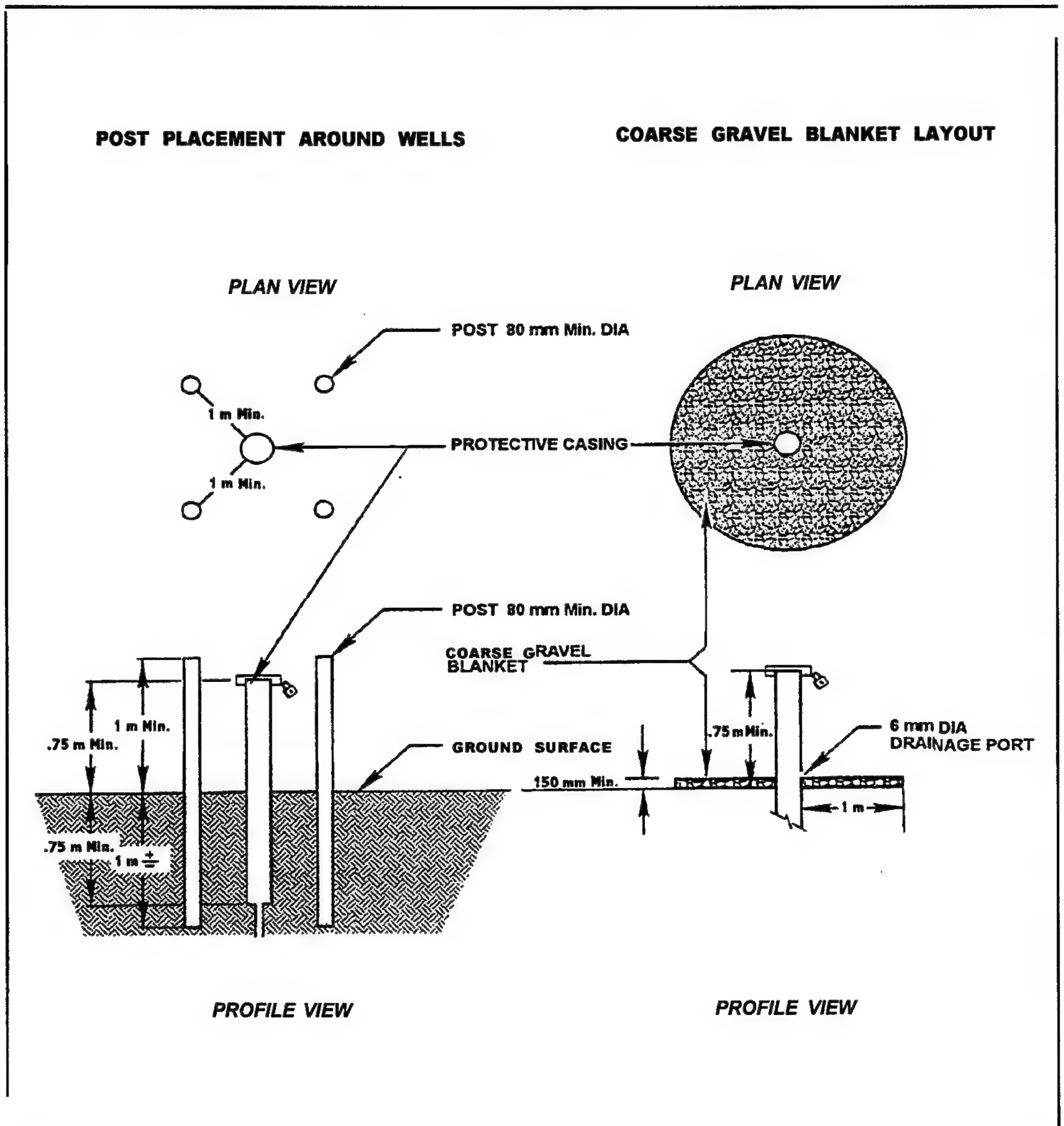


Figure 5-4. Post placement and gravel blanket layout around wells. (Adapted from a figure provided by International Technology Corporation)

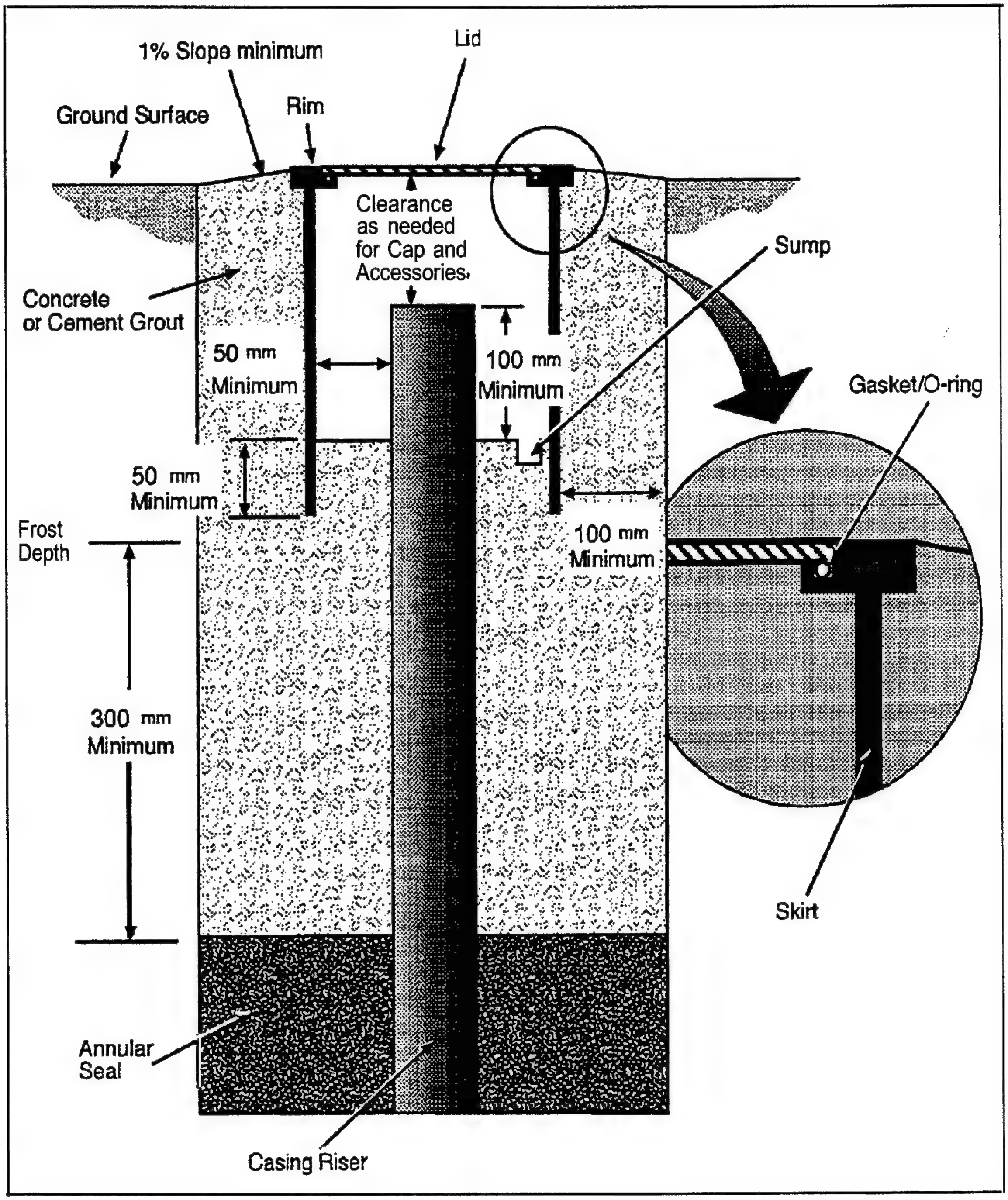


Figure 5-5. Schematic construction of flush-to-ground completion. (Figure provided by Ronald Schalla)

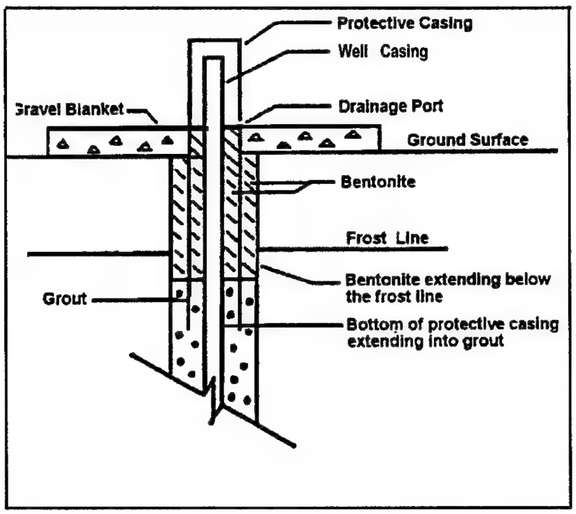


Figure 5-6. Well design parameters to minimize frost heave

5-11. Drilling Fluid Removal

When a borehole, made with or without the use of drilling fluid, contains an excessively thick, particulate-laden fluid that would preclude or hinder the specified well installation, the borehole fluid should be removed or displaced with approved water. This removal is intended to remove or dilute the thick fluid and thus facilitate the proper placement of casing, screen, granular filter, and seal. Fluid losses in this operation should be recorded on the well diagram or boring log and later on the well development record. Any fluid removal prior to well placement should be contingent upon the driller's and the geologist's evaluation of hole stability, e.g., long enough for the desired well and seal placement.

5-12. Drilling Fluid Losses in Bedrock

If large drilling fluid losses occur in bedrock and if the hole is cased to bedrock, the FDO should remove at least three times this volumetric loss prior to well insertion. The intent is to allow the placement of a larger pump in the borehole than otherwise possible in the well casing, thereby reducing subsequent development time and removing the lost water closer to the time of loss. Development of the completed well could then be reduced by a volume equal to that which was removed through the above procedure.

5-13. Well Construction Diagrams

a. Each installed well should be depicted in a well diagram. An example of a well diagram is shown in Figure 5-3. This diagram should be attached to the original bore log for that installation and graphically denote, by depth from ground surface.

(1) The bottom of the boring (that part of the boring most deeply penetrated by drilling and/or sampling) and boring diameter(s).

(2) Screen location.

(3) Joint locations.

(4) Granular filter pack.

(5) Seal.

(6) Grout.

(7) Cave-in.

(8) Centralizers,

(9) Height of riser (stickup) without cap/plug above ground surface.

(10) Protective casing detail.

(a) Height of protective casing without cap/cover, above ground surface.

(b) Bottom of protective casing below ground surface.

(c) Drainage port location and size.

(d) Gravel pad height and extent.

(e) Protective post configuration.

(11) Water level (ASTM D 4750) 24 hours after completion with date and time of measurement.

(12) Estimated maximum depth of frost penetration.

b. Describe the following on the diagram.

(1) The actual quantity and composition of the

grout, bentonite seals, and granular filter pack used for each well.

(2) The screen slot size in millimeters (inches), slot configuration, total open area per meter (foot) of screen, outside diameter, nominal inside diameter, schedule/thickness, composition, and manufacturer.

(3) The material between the bottom of the boring and the bottom of the screen.

(4) The outside diameter, nominal inside diameter, schedule/thickness, composition, and manufacturer of the well casing.

(5) The joint design and composition.

(6) The centralizer design and composition.

(7) The depth and description of any permanent pump or sampling device. For pumps include the voltage, phase requirements, and electrical plug configuration.

(8) The protective casing composition and nominal inside diameter.

(9) Special problems and their resolutions; e.g., grout in wells, lost casing and/or screens, bridging, casing repairs or adjustments, etc.

(10) The dates and times for the start and completion of well installation.

c. Each diagram should be attached to the original boring log and submitted from the field to the FA.

d. Only the original well diagram and boring log should be submitted to the FA. Carbon, typed, or reproduced copies should be retained by the FDO. A legible copy of the well diagram may be used as a base for the supplemental protection diagram.

e. Special abbreviations used on the well completion diagram should be defined on the diagram.

Chapter 6
Well Development

6-1. General

Well development is the procedure that locally improves or restores the aquifer's hydraulic conductivity and removes well drilling fluids, muds, cuttings, mobile particulates, and entrapped gases from within and adjacent to a newly installed well. The resulting inflow should be physically and chemically representative of that portion of the aquifer adjacent to the screened interval. The appropriate development method/procedure to use will vary according to the hydrologic characteristics of the aquifer, the geologic composition of the screened interval, the drilling method, and the type of well completion. Of the various methods available for use in developing wells in general, mechanical surging, pumping, backwashing, and bailing are best suited. Additional guidance on the development of ground-water monitoring wells may be found in ASTM Standard Guide D 5521.

6-2. Timing and Record Submittal

The final development of monitoring wells should be initiated no sooner than 48 hours after or more than 7 days beyond the final grouting of the well. Predevelopment, or preliminary development may be initiated before this minimum 48 hour period. Preliminary development takes place after the screen, casing and filter pack have been installed, but before the annular seal is installed. Preliminary development is done in order to remove any mud cake that may be on the side of the borehole in a timely manner. Predevelopment is also recommended if the well is installed with the intent of using the natural formation material as the filter pack. Because this type of well design is based on the assumption that well development will remove a significant fraction of the formation materials adjacent to the well screen (therefore causing some sloughing in the borehole), developing the well after installing the annular seal may result in portions of the annular seal collapsing into the vicinity of the well screen. It is not good practice to wait and develop all the monitoring wells on a project after the last one is complete. The record of well development should be submitted to the FA.

6-3. Development Methods

A thorough discussion of monitoring well development methods can be found in ASTM Standard Guide D 5521.

a. Mechanical Surging. Operation of a piston-like device termed a surge block affixed to the end of a length of drill rod, or drill stem, is a very effective development method that can be effective in all diameter of wells, even in stratified formations having variable permeability. The up-and-down plunging action alternately forces water to flow into and out of the well, similar to a piston in a cylinder. The use of a surge block can agitate and mobilize particulates around the well screen. Periods of surging should be alternated with periods of water extraction from the well so that sediment, brought into the well, is removed. Surging should initially be gentle to assure that water can come into the well and that the surge block is not so tight as to damage the well pipe or screen. For short well screens (1.6 m (5 ft) or less) set in a homogeneous formation, the surge block does not have to be operated within the screen interval. However, if the screened interval includes materials of high and low permeabilities, the block may have to be operated gently within the screen.

b. Pumping. A commonly used development method consists of pumping a well at a higher rate than water will be extracted during purging or sampling events. This overpumping, however, is usually only successful in relatively non-stratified, clean-sand formations. By pumping the well at a higher rate than expected during sampling, the mobilized particulates may be removed, thereby providing a cleaner well for sampling. Overpumping should be supplemented with the use of a bottom discharge/filling bailer, (for sediment removal). During development, water should be removed throughout the entire water column in the well by periodically lowering and raising the pump intake. A disadvantage of only pumping the well is that the smaller soil grains of the filter pack may be bridged in the screen or in the filter pack, as the direction of flow is only towards the screen. To overcome this, overpumping is often used in conjunction with backwashing or surging.

c. Backwashing. Backwashing is the reversal of water flow in a well, causing soil particles to dislodge that may have become wedged in or bridged around the screen due to overpumping of the well. Backwashing when supplemented with overpumping, facilitates the removal of fine-grained materials from the formation surrounding the borehole. A commonly used backwashing procedure called "rawhiding" consists of starting and stopping the pump intermittently to allow the rising water in the well pipe to fall back into the well. This backwashing procedure produces rapid changes in the pressure head within the well. If rawhiding is to be used, there cannot be a backflow prevention valve in the pump or eductor line. Another method of backwashing is to pump water into the well in sufficient volume to maintain a

head greater than that in the formation. This method of backwashing should only be done when the water pumped into the well is of known and acceptable chemistry. The impact of added water on in situ water quality should be evaluated and, this water should be removed by pumping after development is complete. This method of backwashing, not withstanding the quality of water pumped into the well, may not be allowed by local, state, or federal agencies. Do not use this method in cases where the water pumped into the well is potentially contaminated.

d. Bailing. The use of bailers is an effective way of manually developing small diameter wells that have a high static water table or are relatively shallow in depth (<4.5 m (15 ft)). As the diameter of the bailer is commonly close to the same diameter as the well screen, the bailer agitates the water in the well in much the same manner as a surge block, but to a lesser extent. It is good practice to surge the well using the bailer for 10 to 20 minutes prior to beginning bailing. To have its most effective surging action, the bailer should be operated throughout the screened interval. Bottom loading bailers can extract sediment that has settled to the bottom of the well by rapid short upward/down motions of the bailer at the bottom of the well which stir up the sediment and take it into the bailer. Pumps may be replaced by bottom filling bailers where well size or slow recharge rates restrict pump usage. Bailers should not be left inside the wells after development is completed. Such storage promotes accidental bailer release or loss down the well and inhibits convenient and accurate water-level measurements.

e. High-velocity hydraulic jetting. Another effective method available for use in developing some monitoring wells, is high-velocity hydraulic jetting. This method employs several horizontal jets of water operated from inside the well screen so that high-velocity streams of water exit through the screen and loosen fine-grained material and drilling mud residue from the formation. The loosened material moves inside the well screen and can be removed from the well by concurrent pumping or by bailing. Because of the size of the equipment required, this method is more easily applied to wells of 100 mm (4 in.) or greater diameter. Jetting is particularly successful in developing highly stratified unconsolidated formations, consolidated bedrock wells, large-diameter wells, and natural formation wells. Jetting is generally simple to use, effectively rearranges and breaks down bridging in the filter pack, and effectively removes mud cakes around screen. The disadvantage of using jetting even in ideal conditions is the introduction of foreign water and possible contaminants into the aquifer. Jetting is not effective in cases where slotted pipe is used for the screen. Jetting is much more effective where continuous-wrap v-wire screens, having a greater open area, are used.

f. Special Concerns.

(1) Where monitoring well installations are made in formations that have low hydraulic conductivity, none of the preceeding well development methods may be found to be completely satisfactory. In this situation clean water can be circulated down the well casing, out through the well intake and gravel pack, and up the open borehole prior to placement of the grout or seal in the annulus. Relatively high water velocities can be maintained, and the mud cake from the borehole wall will be broken down effectively and removed. Flow rates should be controlled to prevent floating the gravel pack out of the borehole. Because of the relatively low hydraulic conductivity of geologic materials outside the well, a negligible amount of water will penetrate the formation being monitored. However, immediately following the procedure, the well sealant should be installed and the well pumped to remove as much of the water used in the development process as possible (Barcelona et al. 1985). Adding water to the well for flushing should only be done, however, when no better options are available. In some fine grained deposits vigorous development can be detrimental to the well. If vigorous development is attempted in such wells, the turbidity of water removed from the well may actually increase many times over. In some fine-grained formation materials, no amount of development will measurably improve formation hydraulic conductivity or the hydraulic efficiency of the well. Alternative sampling methods, such as lysimeters (ASTM D 4696), should be considered in low conductivity formations.

(2) Drilling methods. The drilling process influences not only development procedures but also the intensity with which these procedures must be applied. Typical problems associated with special drilling technologies that must be anticipated and overcome are: 1) When drilling an air rotary borehole in rock formations, fine particulate matter typically builds up on the borehole walls and plugs fissures, pore spaces, bedding planes and other permeable zones. The matter must be removed and the openings restored by the development process; 2) If casing has been driven or if augers have been used, the interface between the natural formation and the casing or the auger flights are "smeared" with fine particulate matter that must subsequently be removed in the development process; 3) If a mud rotary technique is used, a mud cake builds up on the borehole wall that must be removed during the development process; and 4) If there have been any additives, as may be necessary in mud rotary, cable tool or augering procedures, the

development process must attempt to remove all of the fluids that have infiltrated into the natural formation (EPA/600/4-89/034). A comparison of the advantages and disadvantages of various drilling methods is in Table 3-1.

6-4. Development Criteria

a. Development should proceed until the following criteria are met:

(1) Satisfaction of applicable federal, state, and local regulatory requirements. Some of these requirements may specify that development continue until the readings for some indicator parameters like pH, conductivity, temperature, oxidation-reduction potential (ORP), dissolved oxygen (DO), or turbidity have stabilized; e.g., vary within a specified range. Stabilization is commonly considered to have been achieved after all parameters have stabilized for three successive readings. Generally three successive readings should be within ±0.2 for pH, ±3% for conductivity, ±10 mV for oxidation-reduction potential (ORP), ±1 degree Celsius for temperature, and ±10% for turbidity and DO. In general the order of stabilization is pH, temperature, and conductivity, followed by ORP, DO and turbidity (Puls and Barcelona 1996).

(2) The well water is clear to the unaided eye and the turbidity of the water removed is at some specified level. Some regulators may require that the turbidity, as measured in nephlometric turbidity units (NTUs), be less than 5 NTUs. It should be noted that natural turbidity levels in ground water may exceed 10 NTUs. Turbidity is always the last indicator parameter to stabilize. There are instances where minimizing turbidity will result in a sample that is not representative of the water that is moving through the formation. If the ground water moving through the formation is, in fact, turbid, or if there is free product moving through the formation, then some criteria may cause a well to be constructed such that the actual contaminant that the well was installed to monitor will be filtered out of the water. Therefore, it is imperative that the design, construction and development of the monitoring well be consistent with the objective of obtaining a sample that is representative of conditions in the ground.

(3) The sediment thickness remaining within the well is less than 1 percent of the screen length or less than 30 mm (0.1 ft) for screens equal to or less than 3 m (10 ft) long.

(4) A minimum removal of three times the standing water volume in the well (to include the well screen and casing plus saturated annulus, assuming 30 percent annular porosity). **IN ADDITION** to the "three times the standing water volume" criteria, further volumetric removal should be considered as follows:

(a) For those wells where the boring was made without the use of drilling fluid (mud and/or water), but water was added to the well during well installation, then three times the amount of any water unrecovered from the well during installation should be removed (in addition to three times the standing volume).

(b) For those wells where the boring was made or enlarged (totally or partially) with the use of drilling fluid (mud and/or water), remove three times the measured (or estimated) amount of total fluids lost while drilling, plus three times that used for well installation (in addition to three times the standing volume).

(5) If the primary purpose of development is to rectify damage done during drilling to the borehole wall and the adjacent formation, the time for development may be based on the response of the well to pumping (ASTM D 4050). An improvement in recovery rate of the well indicates that the localized reduction in hydraulic conductivity has been effectively rectified by development. A commonly used method for determining hydraulic conductivity is the instantaneous change in head, or slug test. The slug test method involves causing a sudden change in head in the well and measuring the water level response within the well. Head change can be induced by suddenly injecting or removing a known quantity or "slug" of water into the well. However, instead of injecting a "slug" of water, a solid or mechanical slug of known volume should be used. The mechanical slug may be constructed of a section of weighted pipe, of known volume, capped on both ends. Water level and elapsed-time data can be recorded with a data logger and pressure transducer. Both "rising heads" and "falling heads" are recorded. Guidance on conducting slug tests may be found in ASTM Standard D 4044.

b. Prior to placement of the seal, if the borehole contains an excessively thick, particulate-laden fluid which would hinder proper well installation, this fluid should be diluted and/or flushed with clean water and purged from the well. Water should not be added to a well as part of development once the initial bentonite seal atop the filter pack is placed. It is essential that any water added to the well is of known and acceptable chemistry. The impact of added water on in situ water quality should be evaluated and removed after development is complete.

c. The use of air to develop a well **SHOULD NOT** be allowed. The introduction of air into a well enhances the occurrence of chemical, physical, and biological changes to the local aquifer system monitored by the well. Furthermore, procedures involving compressed air at HTW sites increase potential exposure/health risks to site personnel from the volatilization and misting of the aerated water. If air development is deemed the most appropriate method for a site, the above factors should be evaluated and mitigation procedures documented in the drilling plan.

d. If any of the following circumstances occur, the FA should be contacted for guidance:

(1) Well recharge so slow that the required volume of water cannot be removed during 48 consecutive hours of development;

(2) Persistent water discoloration after the required volumetric development; and

(3) Excessive sediment remaining after the required volumteric removal.

6-5. Development-Sampling Break

Time should be allowed for equilibration of the well with the formation after development before sampling of the well is undertaken. Well development should be completed at least 14 days before well sampling. The intent of this hiatus is to provide time for the newly installed well and backfill materials to surficially equilibrate to their new environment and for that environment to re-stabilize after the disturbance of drilling. Though a significant volume of water may be pulled through the well during development, the well and granular backfill surfaces over which this water passes are not likely to be at chemical equilibrium with the aquifer. Intuitively, the hiatus allows time for that equilibrium to be created, thereby enhancing the probability of the resulting sample to be more representative of the local aquifer. The 14-day hiatus is a "rule-of-thumb," unsubstantiated by rigorous scientific analysis. If a different value is proposed based upon technical data or overall project considerations, such a change should be evaluated and, if deemed appropriate, implemented. Generally, high permeability formations require less time (e.g., several days) to equilibrate than low permeability formations (e.g., several weeks). The FSP should state the amount of time that will be required to permit the equilibration of the monitoring well following development and prior to sampling and the justification for selection of that time interval.

6-6. Development Water Sample

For each well, a 0.5 L (1-pint) sample of the last water to be removed during development should be placed in a clear glass jar and labeled with well number and date. No preservation of these samples is required. Each sample should be individually agitated and immediately photographed close-up by the FDO with a 35-mm camera and color print film, using a back-lit setup to show water clarity. These photos, minimally 125 mm x 175 mm (5 in. x 7 in.), individually identified with project name, well number, and photo date, should be provided to the FA after all wells are developed. The film negatives should be provided to the FA after the FA has received the prints. The FDO should dispose of these water samples in the same manner as the rest of the water removed during development.

6-7. Well Washing

Part of well development should include the washing of the entire well cap and the interior of the well casing above the water table using only water from that well. The result of this operation will be a well casing free of extraneous materials (grout, bentonite, sand, etc.) inside the well cap and blank casing, between the top of the well and the water table. This washing should be conducted before and/or during development, not after development.

6-8. Well Development Record

The following data should be recorded as part of development and submitted to the FA:

a. Project name, location.

b. Well designation, location.

c. Date(s) and time(s) of well installation.

d. Date(s) and time(s) of well development.

e. Static water level from top of well casing before and 24 hours after development.

f. Quantity of mud/water:

(1) Lost during drilling.

(2) Removed prior to well insertion.

(3) Lost during thick fluid displacement.

(4) Added during granular filter placement.

g. Quantity of fluid in well prior to development:

(1) Standing in well.

(2) Contained in saturated annulus (assume 30 percent porosity).

h. Field measurement of pH (ASTMs D1293 and D5464), conductivity (ASTM D1125), oxidation-reduction (redox) potential (ASTM D1498), dissolved oxygen (ASTMs D888 and D5462), turbidity (ASTM D1889), and temperature (EPA Method 170.1) before, twice during, and after development using an appropriate device and method. Field methods for these parameters can also be found in EPA 600/4-79/020, and Standard Methods.

i. Depth from top of well casing to bottom of well.

j. Screen length.

k. Depth from top of well casing to top of sediment inside well, before and after development (from actual measurements at time of development).

l. Physical character of removed water, to include changes during development in clarity, color, particulates, and any noted odor.

m. Type and size/capacity of pump and/or bailer used.

n. Description of surge technique, if used.

o. Height of well casing above ground surface (from actual measurement at time of development).

p. Typical pumping rate.

q. Estimated recharge rate.

r. Quantity of fluid/water removed and time for removal (present both incremental and total values).

6-9. Potential Difficulties

Many difficulties may arise during development and presample purging. Some are readily apparent but troublesome to resolve; e.g., a well that is easily pumped dry but slow to recharge or one that will not produce clear, particulate-free water. Other difficulties are not easily observed but may bias the analytical results, e.g., pulling-in distant parts of the aquifer in an effort to achieve a repetitively consistent field reading or aerating the aquifer adjacent to the well in a hurried attempt at well development. In addition, the unanticipated presence of dense (or light) nonaqueous phase liquids (NAPL) in the screened interval would affect the chemical homogeneity of that interval and hydrologic parameters derived from that well. The anticipation, evaluation, and tentative solution for these problems should begin early in the formulation of each drilling plan.

Chapter 7
Well and Boring Acceptance Criteria

7-1. Well Criteria

Wells should be acceptable to the FA. Well acceptance should be on a case-by-case basis. The following criteria should be used along with individual circumstances in the evaluation process.

a. The well and material placement should meet the construction and placement specifications of the drilling and well installation plan unless modified by amendments.

b. Wells should not contain portions of drill casing or augers unless they are specified in the drilling plan as permanent casing.

c. All well casing and screen materials should be free of any unsecured couplings, ruptures, or other physical breakage/defects before and after installation.

d. The annular material (filter pack, bentonite, and grout) of the installed well should form a continuous and uniform structure, free of any detectable fractures, cracks, or voids.

e. Any casing or screen deformation or bending should be minimal to allow the insertion and retrieval of the pump and/or bailer optimally designed for that size casing, e.g., a 75 mm (3-in.) pump in a 100 mm (4-in.) schedule 80, PVC casing is optimal; a 50 mm (2-in.) pump in a 100 mm (4-in.) casing is not optimal.

f. All joints should be constructed to provide a straight, nonconstricting, and watertight fit.

g. Completed wells should be free of extraneous objects or materials; e.g., tools, pumps, bailers, packers, excessive sediment thickness, grout, etc. This prohibition should not apply to intentionally installed equipment per drilling plan.

h. For those monitoring wells where the screen depth was determined by the FDO, the well should have sufficient free water at the time of the water-level measurement to obtain a representative groundwater level for that well. These same wells should have sufficient free water at the time of initial sampling, which is representative of the desired portion of the aquifer for the intended chemical analyses.

i. All boring logs, well diagrams, development records, topographic survey data, and related photographs and negatives should have been completed per the drilling plan and received by the FA.

j. Keys to the padlocks securing the well covers should be in the possession of the FA and the FA project representative prior to well acceptance.

7-2. Abandoned/Decommissioned Borings and Wells

Borings not completed as wells should be abandoned/ decommissioned per paragraph **3-14** of this manual.

7-3. Well and Boring Rejection

Wells and borings not meeting drilling plan criteria are subject to rejection by the FA.

Chapter 8
Water Levels

8-1. Measurement Frequency and Coverage

The frequency of water-level measurement is project related. At a minimum, for those projects involving the installation of any monitoring wells, at least one complete set of *static* water-level measurements should be made over a single, consecutive 10-to-12-hour period for all project-related wells, both newly installed and specified existing wells. These measurements should be taken at least 24 hours after development or sampling. Static levels in borings not converted to wells should be included if practical and technically appropriate. This set of measurements should include a notation for the presence of any streams, lakes, and/or open water bodies (natural and man-made) within proximity, e.g., about 90 m (300 ft) of these wells. Elevation measurements of any surface water bodies should be a consideration within the drilling and well installation plan.

8-2. Vertical Control

The depth to groundwater should be measured and reported to the nearest 3 mm (0.01 ft). Measurement should be made from the highest point on the rim of the well casing or riser (not protective casing). This same point on the well casing should be surveyed for vertical control. The surveyed mark on the top of the casing should be permanently marked with a notch cut in the casing to ensure that depth to water is always measured from the same elevation. Surface water levels should be measured at least to the nearest 30 mm (0.1 ft) using an adjacent temporary or permanent survey marker as a datum for current and future reference.

8-3. Reporting and Usage

All water level data should be presented as elevations in tabular form. Where sufficient data points exist, the elevations should be contoured to denote flow directions, gradients, and any hydrological interconnections between aquifers and surface water bodies.

8-4. Methods

Guidance on determining liquid levels in a borehole or monitoring well may be found in ASTM D 4750.

Chapter 9
Topographic Survey

9-1. Licensing

All topographic survey efforts conducted under contract should be certified by a surveyor with a current surveyor's license in the project state. Any licensing requirements within the project state for contract or Corps of Engineers surveyors should be determined by the FA.

9-2. Horizontal Control

Each boring and/or well installation should be topographically surveyed to determine its map coordinates referenced to either a Universal Transverse Mercator (UTM) grid or the State Plane Coordinate System (SPCS). These surveys should be connected to the UTM or SPCS by third order, Class II control surveys in accordance with the Standards and Specifications for Geodetic Control Networks (Federal Geodetic Control Committee 1984). If the project is in an area remote from UTM or SPCS benchmarks and such horizontal control is not warranted, then locations measured from an alternate system depicted on project plans may suffice, at least on a temporary basis. All borings, wells, temporary and/or permanent markers should have an accuracy of ±300 mm (±1 ft) within the chosen system.

9-3. Vertical Control

Elevations for the natural ground surface (not the top of the coarse gravel blanket) and a designated point on the rim of the uncapped well casing (not protective casing) for each bore/well site should be surveyed to within 3 mm (±0.01 ft) and referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) or the North American Vertical Datum, 1988 Adjustment (NAVD 88). These surveys should be connected by third order leveling to the NGVD of 1929 or NAVD 1988 in accordance with the Standards and Specifications for Geodetic Control Networks. If the project is in an area remote from NGVD benchmarks and such vertical control is not warranted, then elevations measured from a project datum may suffice, at least on a temporary basis.

9-4. Field Data

The topographic survey should be completed as near to the time of last well completion as possible. Survey field data (as corrected), to include loop closures and other statistical data in accordance with the Standards and Specifications referenced above, should be provided to the FA. Closure should be within the horizontal and vertical limits given above. These data should clearly be listed in tabular form including the coordinates (and system) and elevation (ground surface and top of well) as appropriate, for all borings, wells, and reference marks. All permanent and semipermanent reference marks used for horizontal and vertical control, benchmarks, caps, plates, chiseled cuts, rail spikes, etc., should be described in terms of their name, character, physical location, and reference value. These field data should become part of the project records maintained by the FA.

9-5. Geospatial Data Systems

Geospatial data is non-tactical data referenced either directly or indirectly to a location on the earth. Geospatial data identifies the geographic location and characteristics of natural or constructed features and boundries on the earth. Monitoring wells and the data generated from them meet these definitions and therefore must be documented according to the metadata standards cited in ER 1110-1-8156. ER 1110-1-8156 requires geospatial data to be documented using the Federal Geographic Data Committee Content Standards for Digital Geospatial Metadata. Guidance on geospatial data systems (GDS) may also be found in EM 1110-1-2909 and ASTM Standard Specification D 5714.

Chapter 10
Borehole Geophysics

10-1. Usage and Reporting

The use of geophysical techniques, if required, should be specified in the drilling plan. In the absence of this specification, the FDO should consider these techniques for site-specific applicability to enhance the technical acuity and cost-effectiveness of its efforts. Special applications may be useful in unexploded ordnance detection, disturbed area delineation, contaminant detection, depth to bedrock determination, buried drum detection, borehole and well logging, etc. When approved for use, geophysical techniques should be discussed in the drilling plan to include the purpose; particular method(s) and equipment; selection rationale; physical and procedural assumptions; limitations (theoretical and site specific); resolution; accuracy; and quality control. Safety aspects of geophysical applications should be included in the safety plan, especially for those areas where induced electrical currents or seismic waves could detonate unexploded ordnance or other explosive materials.

10-2. Methods

General geophysical methodology is covered in EM 1110-1-1802. Geophysical techniques applied to HTRW studies are found in USEPA 625/R-92/007, 600/2-87/078, 600/7-84/064, and in Benson, Glaccum, and Noel (1982). Additional guidance on planning and conducting borehole geophysical logging can be found in ASTM Standard Guide D 5753.

Chapter 11
Vadose Zone Monitoring

11-1. Usage and Reporting

Data acquisition from the vadose (unsaturated) zone should be addressed on a case-by-case basis. The use of lysimeters in a silica flour matrix, soil-gas monitors, and analysis of bulk soil samples are mechanisms which may be employed.

When vadose zone monitoring is proposed,the drilling plan should include the purpose; particular method(s) and equipment; selection rationale; physical and procedural assumptions; limitations (theoretical and site-specific); quality control; and any analytical variances from the current USACE protocol.

11-2. Methods

Guidance on vadose zone monitoring may be found in ASTM Standard Guides D 4696 and D 5126. A general discussion of vadose monitoring can be found in Everett, Wilson, and Hoylman (1984).

Chapter 12
Data Management System

12-1. Benefits

The use of a computerized system will enhance reporting procedures by means of intra-report consistency, reduction of editorial review, broadening of graphical capabilities, and ease of data retrieval for project review and inter-project comparisons. Each FA is encouraged to utilize a computerized data management system for technical data.

12-2. Assistance Sources

Several existing systems are available for utilization by individual FAs. New systems are also being developed at the DOD level to combine existing systems and reduce redundancy in data reporting systems. Guidance on boring log data management may be found in the USACE Waterways Experiment Station contract report GL-93-1. Assistance can be obtained from the HTRW CX, at CENWO-HX-G.

12-3. Geospatial Data Systems

Geospatial data is non-tactical data referenced either directly or indirectly to a location on the earth. Geospatial data identifies the geographic location and characteristics of natural or constructed features and boundries on the earth. Monitoring wells, and the data generated from them, meet these definitions and therefore must be documented according to the metadata standards cited in ER 1110-1-8156. ER 1110-1-8156 requires geospatial data to be documented using the Federal Geographic Data Committee Content Standards for Digital Geospatial Metadata. Guidance on geospatial data systems (GDS) may also be found in EM 1110-1-2909 and ASTM D 5714.

Appendix A
References

A-1. Required Publications

29 CFR 1910.120
Code of Federal Regulations, 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response.

29 CFR 1926
Code of Federal Regulations, 29 CFR 1926, Safety and Health Regulations for Construction.

ER 385-1-92
Safety and Occupational Health Document Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) and Ordnance and Explosive Waste (OEW) Activities.

ER 1110-1-263
Chemical Data Quality Management for Hazardous Waste Remedial Activities.

ER 1110-1-1803
Care, Storage, Retention, and Ultimate Disposal of Exploratory and Other Cores.

ER 1110-1-8156
Policies, Guidance, and Requirements For Geospatial Data and Systems.

ER 1110-2-1807
Use of Air Drilling in Embankments and Their Foundations.

ER 1165-2-132
Hazardous, Toxic, and Radioactive Waste (HTRW) Guidance for Civil Works Projects.

EM 200-1-2
Technical Project Planning (TPP) Process.

EM 200-1-3
Requirements for the Preparation of Sampling and Analysis Plans.

EM 385-1-1
Safety and Health Requirements Manual.

EM 1110-1-1802
Geophysical Exploration.

EM 1110-1-1804
Geotechnical Investigations.

EM 1110-1-1906
Soil Sampling.

EM 1110-1-2909
Geospatial Data and Systems.

EM 1110-2-1906
Laboratory Soils Testing.

EM 1110-2-3506
Grouting Technology.

FM 5-410
U.S. Army Field Manual, " Military Soils Engineering."

FM 5-430
U.S. Army Field Manual, "Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations."

FM 5-484
U.S. Army Field Manual, "Multiservice Procedures For Well-Drilling Operations."

TM 5-818-2
U.S. Army Technical Manual, "Pavement Design For Seasonal Frost Conditions."

TM 5-818-3
U.S. Army Technical Manual, "Pavement Evaluation For Frost Conditions."

TM 5-852-6
U.S. Army Technical Manual, "Arctic and Subarctic Construction: Calculation Methods For Determination of Depth of Freeze and Thaw In Soils."

CEGS 02522
U.S. Army Corps of Engineers Guide Specification, "Ground-Water Monitoring Wells."

CWGS 02010
U.S. Army Corps of Engineers Guide Specification, "Subsurface Drilling, Sampling, and Testing."

GL-93-1
U.S.Army Corps of Engineers, Contract Report GL-93-1 (July 93), User's Guide for the Boring Log Data Manager, Version 2.0, Computer Applications in Geotechnical Engineering (CAGE) Project, Geotechnical Laboratory, Waterways Experiment Station, 3909 Halls Ferry Road,

Vicksburg, MS 39180-6199.

Benson, Glaccum, and Noel 1982
Benson, R.C., Glaccum, R.A., and Noel, M.R. 1982. "Geophysical Techniques for Sensing Buried Wastes and Waste Migration," Environmental Monitoring Systems Laboratory, U.S. EPA, Las Vegas, NV, EPA/600/7-8-4/064.

Colangelo 1988
Colangelo, Robert V. 1988. "Inert Annular Space Materials, the Acid Test," Ground Water Monitoring Review, Spring 1988.

Driscoll 1986
Driscoll, Fletcher G. 1986. "Groundwater and Wells," Johnson Filtration Systems Inc., St Paul, MN.

Federal Geodetic Control Committee 1984
"Standards and Specifications for Geodetic Control Networks," National Oceanic and Atmospheric Administration, Rockville, MD.

Federal Geographic Data Committee 1994
"Content Standards for Digital Geospatial Metadata," 1994, FGDC Secretariat, USGS, 590 National Center, 12201 Sunrise Valley Drive, Reston, VA, 20192.

Hsai-Wong Fang 1991
Hsai-Wong Fang. 1991. "Foundation Engineering Handbook."

Murhpy 1985
Murphy, William L. 1985. "Geotechnical Descriptions Of Rock and Rock Masses," Technical Report GL-85-3, U.S.Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

National Sanitation Foundation
National Sanitation Foundation, NSF Standard 14: "Plastics Piping System Components and Related Materials," 3475 Plymouth Rd., P.O. Box 130140, Ann Arbor, MI 48105.

Oliver 1997
Oliver, Bob 1997. "Bentonite Grouts vs. Cement Grouts," National Drillers Buyers Guide, May 1997.

Puls and Barcelona 1996
Puls, Robert W., and Barcelona, Michael J. 1996. "Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures," U.S. EPA, Ground Water Issue, April 1996, EPA/540/S-95/504, Robert S. Kerr Environmetal Research Center, Ada, OK.

Spigolon 1993
Spigolon, S. Joseph. 1993. "Geotechnical Factors in the Dredgeability of Sediments: **Report 1**, Geotechnical Descriptors For Sediments To Be Dredged," Contract Report DRP-93-3, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Standard Methods
"Standard Methods for the Examination of Water and Wastewater," American Public Health Assoc. (APHA), American Water Works Assoc. (AWWA), and the Water Pollution Control Federation (WPCF), 19th Edition, 1995.

USEPA, EPA/510/B-97/001
"Expedited Site Assessment Tools For Underground Storage Tank Sites," U.S. EPA, Office of Solid Waste, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/530/SW-86/055, OSWER Directive 9950.1
"RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD)," U.S. EPA, Office of Solid Waste, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/540/G-88/003, OSWER Directive 9283.1-2
"Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites," U.S.EPA, Office of Emergency and Remedial Response, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/540/G-91/009
"Management of Investigation-Derived Wastes During Site Inspections," U.S. EPA, Office of Research and Development, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/540/S-95/503
"Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation," Ground Water Issue, July 1995, U.S. EPA, Robert S. Kerr Environmental Laboratory, Ada, OK.

USEPA, EPA/600/2-87/078
"Nondestructive Testing Techniques to Detect Contained Subsurface Hazardous Waste," U.S. EPA, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/600/4-79/020
"Methods for Chemical Analysis of Water and Wastes," U.S.EPA, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/600/4-89/034
"Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells," U.S. EPA, Office of Research and Development, 401 M St., SW, Washington, DC 20460.

USEPA, EPA/600/7-84/064
"Geophysical Techniques for Sensing Buried Wastes and Waste Migration," U.S. EPA, Environmental Monitoring Systems Laboratory, Las Vegas, NV 89114.

USEPA, EPA/625/6-87/016
"Handbook: Ground Water," U.S.EPA, Robert S. Kerr Environmental Reseach Laboratory, Ada, OK 74820.

USEPA, EPA/625/12-91/002
"Description and Sampling of Contaminated Soils: A Field Pocket Guide," U.S. EPA, Center for Environmental Research Information, 26 W. MLK Dr., Cincinati, OH 45268.

USEPA, EPA/625/R-92/007
"Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites," U.S. EPA, Office of Research and Development, Washington, DC 20460.

USEPA, EPA/625/R-93/003a
"Subsurface Characterization and Monitoring Techniques: A Desk Reference Guide, Volume I: Solids and Ground Water," U.S. EPA, Office of Research and Development, Washington, DC 20460.

USEPA, EPA/625/R-94/003
"Alternative Methods for Fluid Delivery and Recovery," U.S. EPA, Office of Research and Development, Washington, DC 20460.

USEPA, EPA/813/B-92/002
"Definitions for the Minimum Set of Data Elements for Ground Water Quality," U.S. EPA, Office of Ground Water and Drinking Water, Washington, DC

USEPA, OSWER Directive 9283.1-06
"Considerations in Ground-Water Remediation at Superfund Sites and RCRA Facilities--Update," 1992, U.S. EPA, Office of Solid Waste and Emergency Response, Washington, DC 20460.

USEPA, OSWER Directive 9345.3-03FS
"Guide to Management of Investigation-Derived Wastes," U.S.EPA, Office of Solid Waste, 401 M St., SW, Washington, DC 20460.

USEPA, SW-846
"Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," U.S.EPA, Office of Solid Waste, 401 M St., SW, Washington, DC 20460.

USGS, WRI Report 96-4233
"Guidelines and Standard Procedures for Studies of Ground-Water Quality: Selection and Installation of Wells, and Supporting Documentation," U.S. Geological Survey, Water-Resources Investigations (WRI) Report 96-4233 (1997), Reston, VA.

USGS, TWRI Book 2 Chapter F1
"Application of Drilling, Coring, and Sampling Techniques To Test Holes and Wells," U.S. Geological Survey, Techniques of Water-Resource Investigations (TWRI) of the USGS, Book 2, Chapter F1 (1989).

ASTM
Annual Book of ASTM Standards, copyright American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, to include the following within this series:

C 150 Specification for Portland Cement

D 888 Test Method for Dissolved Oxygen in Water

D 1125 Test Method for Electrical Conductivity and Resistivity of Water

D 1293 Test Method for pH in Water

D 1498 Practice for Oxidation-Reduction Potential of Water

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils

D 1785 Specification for Polyvinyl Chloride (PVC) Plastic Pipe Schedules 40, 80 and 120

D 1889 Test Method for Turbidity in Water

D 2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

D 2487 Test Method for Classification of Soils for Engineering Purposes.

D 2488 Practice for Description and Indentification of Soils (Visual-Manual Procedures).

D 4044 Test Method (Field Procedure) for Instantaneous Change in Head (Slug Tests) for Determining Hydraulic Properties of Aquifers

D 4050 Test Method (Field Porcedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems

D 4220 Practice for Preserving and Transporting Soil Samples

D 4448 Guide for Sampling Groundwater Monitoring Wells.

D 4696 Guide for Pore-Liquid Sampling from the Vadose Zone

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)

D 5079 Practice for Preserving and Transporting Rock Core Samples

D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites.

D 5092 Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers.

D 5126 Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone

D 5299 Guide for the Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities.

D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock.

D 5462 Test Method for On-Line Measurement of Low Level Dissolved Oxygen in Water

D 5464 Test Methods for pH Measurement of Water of Low Conductivity

D 5521 Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers.

D 5608 Practice for the Decontamination of Field Equipment Used at Low Level Radioactive Waste Sites

D 5714 Specification for Content of Digital Geospatial Metadata

D 5717 Guide for Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers.

D 5737 Guide for Methods for Measuring Well Discharge

D 5753 Guide for Planning and Conducting Borehole Geophysical Logging

D 5778 Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils

D 5781 Guide for the Use of Dual Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices

D 5782 Guide for the Use of Direct Air Rotary Drilling for Geonvironmental Exploration and the Installation of Subsurface Water Quality Montoring Devices

D 5783 Guide for the Use of Direct Rotary Drilling With Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices

D 5784 Guide for the Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices

D 5787 Practice for Monitoring Well Protection.

D 5872 Guide for Use of Casing Advancement Drilling Methods For Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices

D 5875 Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices

D 5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices

D 5978 Guide for Maintenance and Rehabilitation of Ground Water Monitoring Wells

D 6001 Guide for Direct Push Water Sampling for

Geoenvironmental Investigations

D 6067 Test Method for Using the Electronic Cone Penetrometer for Environmental Site Characterization

D 6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations.

D 6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations.

D 6286 Guide for Selection of Drilling Methods for Environmental Site Characterization

F 480 Specifications for Thermoplastic Water Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80.

A-2. Related Publications

Barcelona et al. 1985
Barcelona, Michael J., Gibbs, James P., Helfrich, John A. And Garske, Edward E. 1985. "Practical Guide For Ground-Water Sampling," Illinois State Water Survey, Champaign, IL, ISWS Contract Report 374, and the U.S. EPA EPA/600/2-85/104.

Everett, Wilson, and Hoylman 1984
Everett, L.G., Wilson, L.G., and Hoylman, E. W. 1984. "Vadose Zone Monitoring for Hazardous Waste Sites," Noyes Data Corporation, Park Ridge, NJ.

Geological Society of America
Geological Society of America, GSA Rock Color Chart, RCC001, 1969. Geological Society of America, 3300 Penrose Place,Boulder, CO 80301.

Hales 1995
Hales, Lyndell Z. 1995. "Descriptors For Bottom Sediments To Be Dredged: Summary Report For Work Unit No. 32471," Techncial Report (T.R.) DRP-95-5, U.S. Army Corps of Engineers, Waterways Experiment Station, Dredging Research Program (DRP).

MacBeth
MacBeth, a Division of Kollmorgen Instruments Corp, The Munsell Soil Color Chart, MacBeth, 405 Little Britain Rd., New Windsor, NY 12553.

Appendix B
Abbreviations

AE Architect-Engineer

ASTM American Society for Testing and Materials

CECW-EG Geotechnical and Materials Branch, Engineering Division, Directorate of Civil Works, Headquarters, U.S. Army Corps of Engineers

CEMP-RT Policy and Technology Branch, Environmental Division, Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers

CENWO-HX-G Geoenvironmental and Process Engineering Branch, HTRW Center of Expertise, Omaha District, Missouri River Region

CERCLA Comprehensive Environmental Resource, Compensation, and Liability Act

CFR Code of Federal Regulations

DERP Defense Environmental Restoration Program

EM Engineer Manual

ENG Engineer

FA Field Activity

FDO Field Drilling Organization

FGDC Federal Geographic Data Committee

FSP Field Sampling Plan

GDQM Geotechnical Data Quality Management

GSA Geological Society of America

HQUSACE Headquarters, United States Army Corps of Engineers

HTRW Hazardous, Toxic, and Radioactive Waste

ID Inside Diameter

IDW Investigation-Derived Waste

CX HTRW Center of Expertise

DNAPL Dense Nonaqueous Phase Liquid

DO Dissolved oxygen

DTH Down-the-Hole (Hammer)

MRR Missouri River Region

N Normal

NAPL Nonaqueous Phase Liquid

NAVD North American Vertical Datum

NGVD National Geodetic Vertical Datum

NSF National Sanitation Foundation

NTU Nephelometric Turbidity Unit

OD Outside Diameter

ORP Oxidation-Reduction Potential

OSHA Occupational Safety and Health Administration

OSWER Office of Solid Waste and Emergency Response (EPA)

pH The negative logarithm of the effective hydrogen ion concentration in gram equivalents per liter

PCB Polychlorinated Biphenyl

PTFE Polytetrafluoroethylene

PVC Polyvinyl Chloride

RCRA Resource Conservation and Recovery Act

SAP Sampling and Analysis Plan

SARA Superfund Amendments and Reauthorization Act

SCAPS Site Characterization and Analysis

	Penetrometer System
SPCS	State Plane Coordinate System
SSHP	Site Safety and Health Plan
TSCA	Toxic Substance Control Act
TTIA	Technology Transfer Improvements Act
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator